US008607405B2

(12) **United States Patent**
Reed et al.

(10) **Patent No.: US 8,607,405 B2**
(45) **Date of Patent: Dec. 17, 2013**

(54) **BATTERY POWERED CORDLESS CLEANING SYSTEM**

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(73) Assignee: **Techtronic Floor Care Technology Limited**, Tortola (VG)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 912 days.

(21) Appl. No.: **12/580,878**

(22) Filed: **Oct. 16, 2009**

(65) **Prior Publication Data**

US 2010/0088843 A1 Apr. 15, 2010

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/405,033, filed on Mar. 16, 2009, and a continuation-in-part of application No. 29/326,368, filed on Oct. 16, 2008, now Pat. No. Des. 652,377, and a continuation-in-part of application No. 29/326,362, filed on Oct. 16, 2008, now Pat. No. Des. 615,717, and a continuation-in-part of application No. 29/326,364, filed on Oct. 16, 2008, now abandoned.

(60) Provisional application No. 61/036,720, filed on Mar. 14, 2008, provisional application No. 61/105,891, filed on Oct. 16, 2008, provisional application No. 61/105,899, filed on Oct. 16, 2008, provisional application No. 61/105,896, filed on Oct. 16, 2008.

(51) **Int. Cl.**
A47L 9/28 (2006.01)

(52) **U.S. Cl.**
USPC **15/328**

(58) **Field of Classification Search**
USPC 15/324, 328, 329, 359, 389, 344
See application file for complete search history.

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Westinghouse Vacuum and Battery & Charger photographs, Photos of Battery Pack, Vacuum, Claims, Front View, Side View, Rear View, Charger, Battery Back, and Battery Front, 4 pages, available at least as early as Jul. 9, 2009.

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Primary Examiner — Robert Scruggs
(74) *Attorney, Agent, or Firm* — Michael Best & Friedrich LLP

(57) **ABSTRACT**

A cordless, battery-powered system of cleaning products. The system of cleaning products includes devices such as upright vacuums (e.g., a stick vacuum, a lightweight upright vacuum, etc.), a hand-held vacuum, a carpet-cleaner, a canister vacuum, and the like. Each of the devices is powered by a battery pack which is interchangeable among the devices. The battery pack includes a combination of hardware and software for connecting to, identifying, and communicating with the cleaning products to ensure that each of the products receives the power necessary to ensure optimal performance.

15 Claims, 22 Drawing Sheets

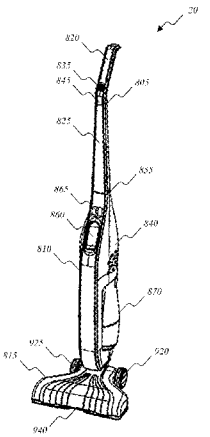

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FIG. 1

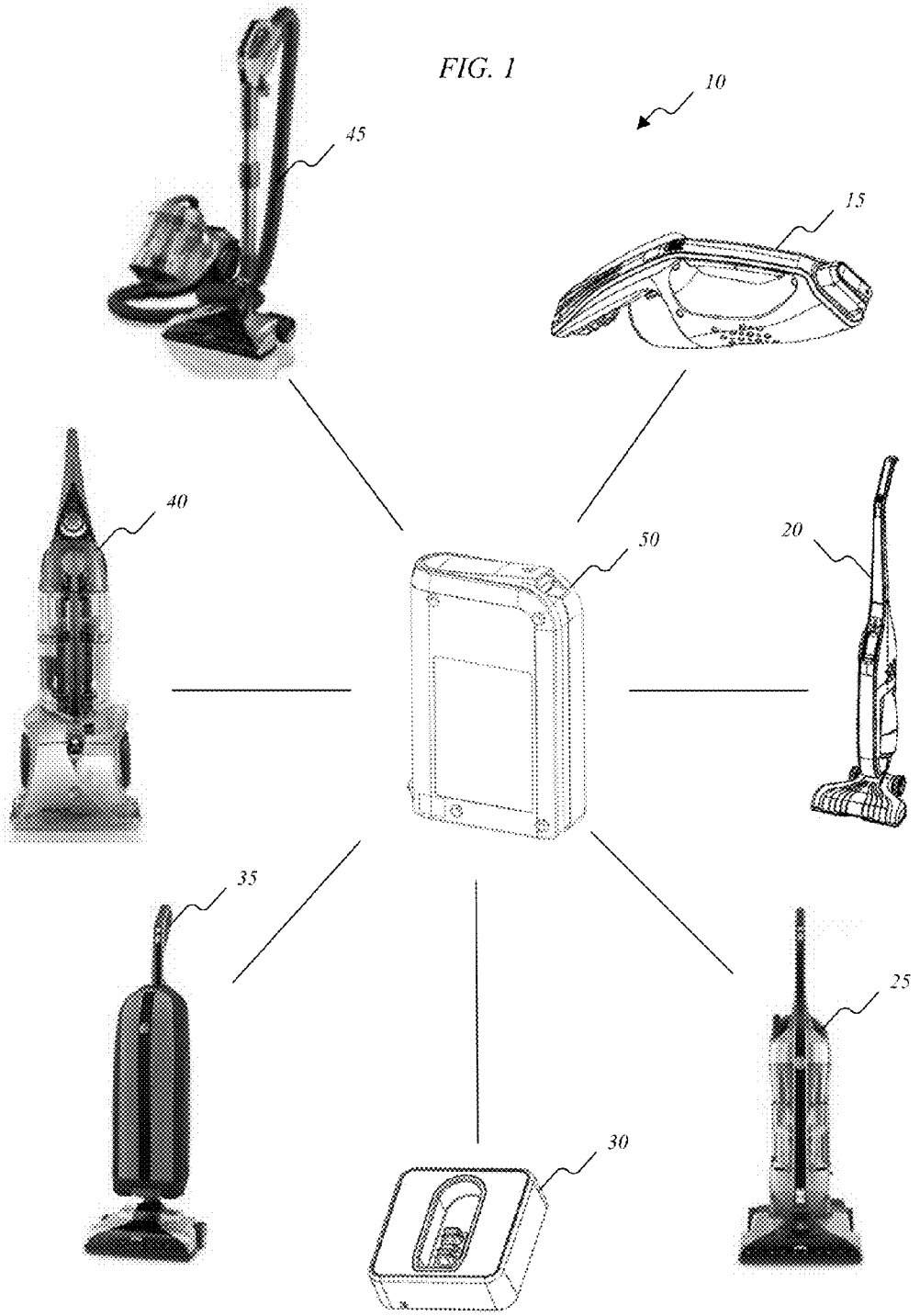


FIG. 2

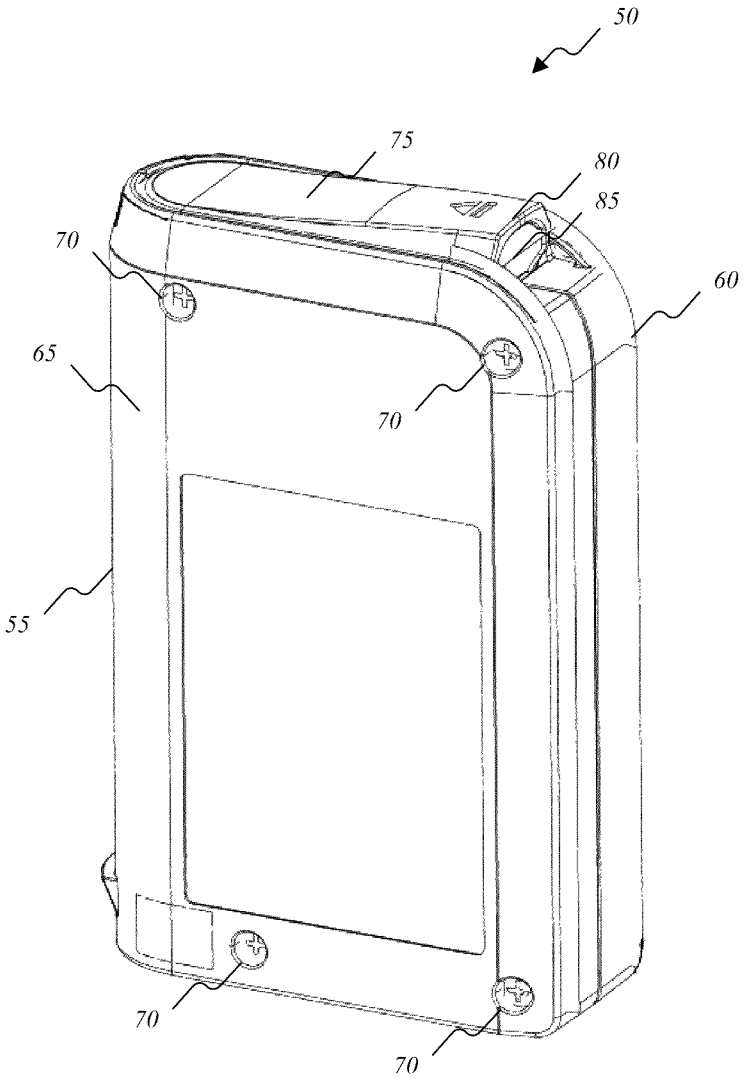


FIG. 3

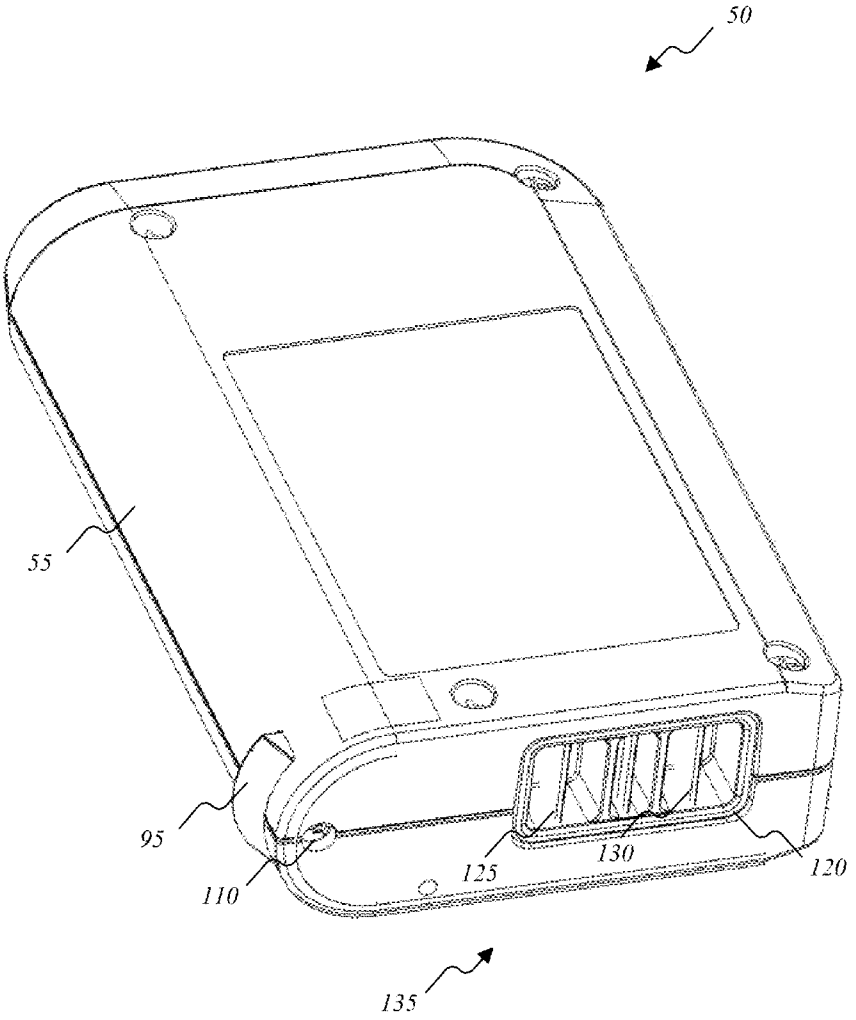


FIG. 4

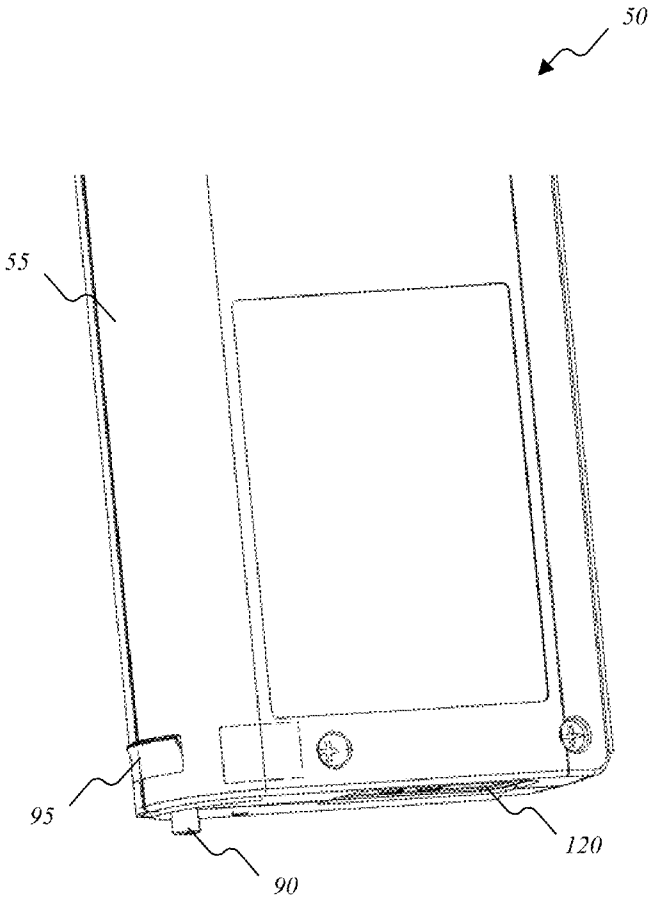


FIG. 5

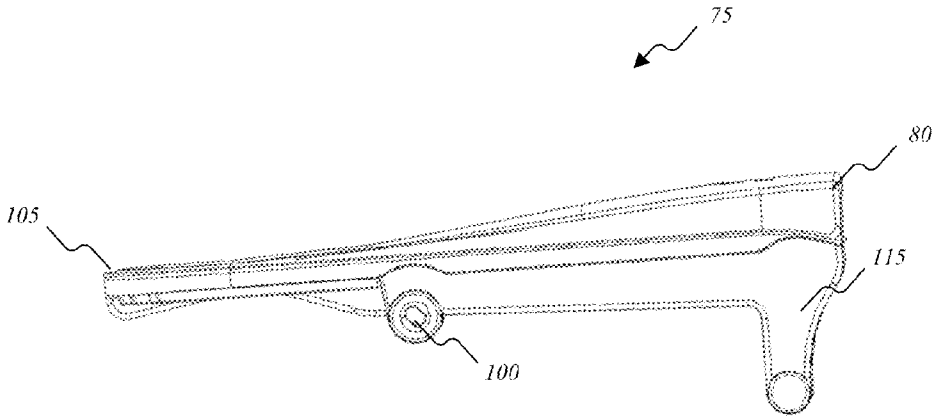


FIG. 6

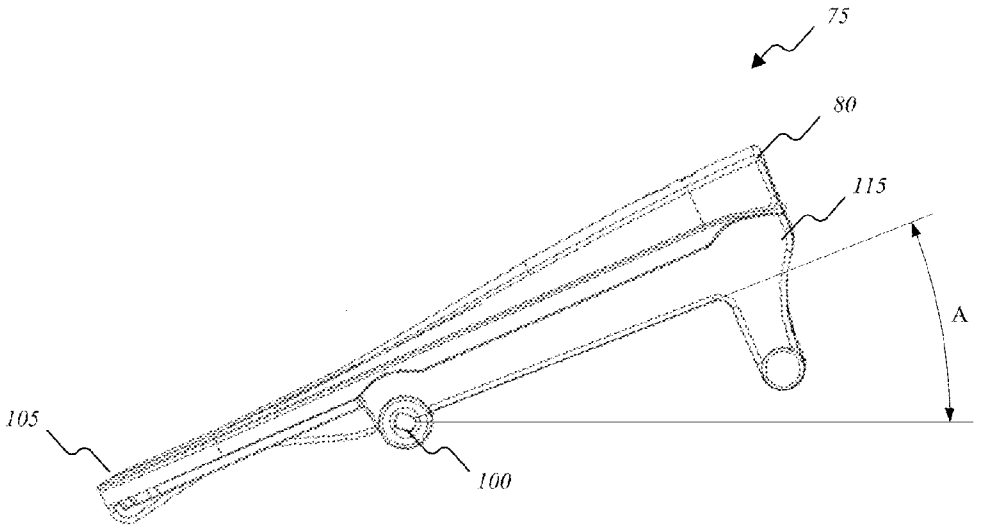


FIG. 8

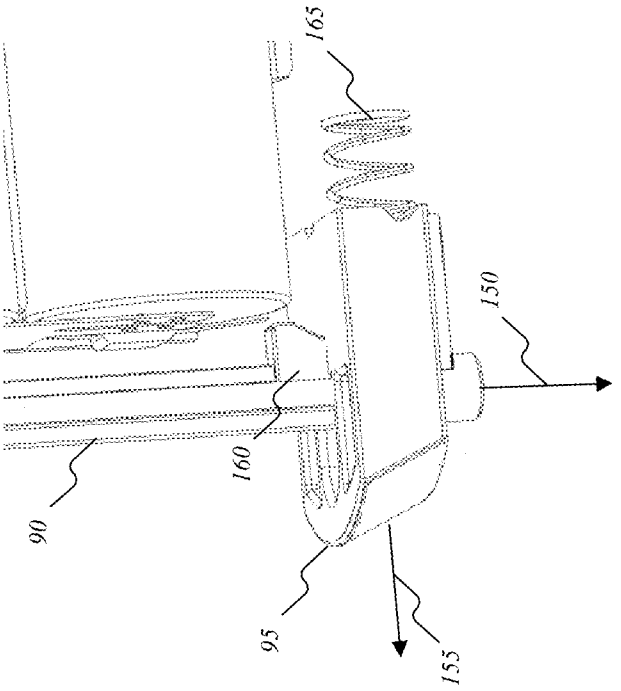


FIG. 7

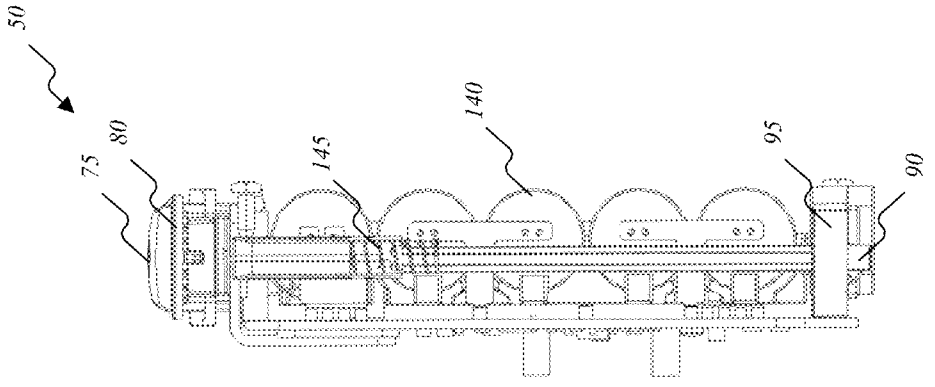


FIG. 10

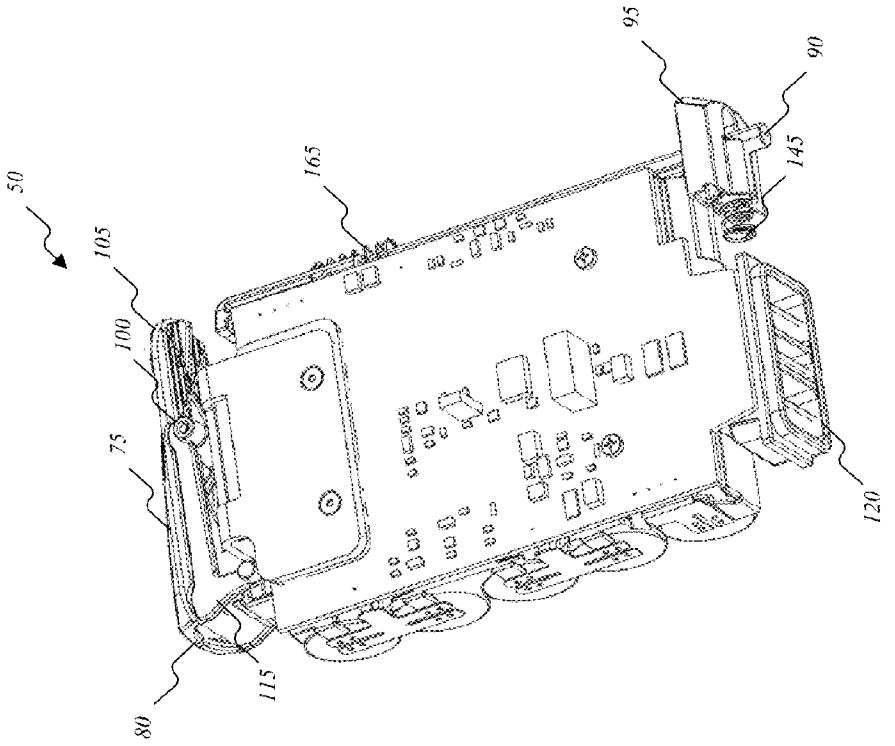
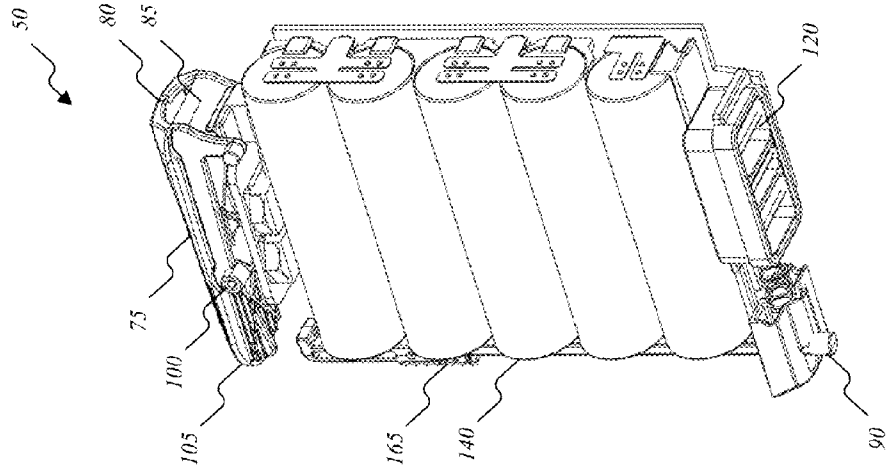

50
105
100
75
80
115
165
95
90
145
120

FIG. 9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80
85
75
100
105
165
140
120
90

FIG. 11

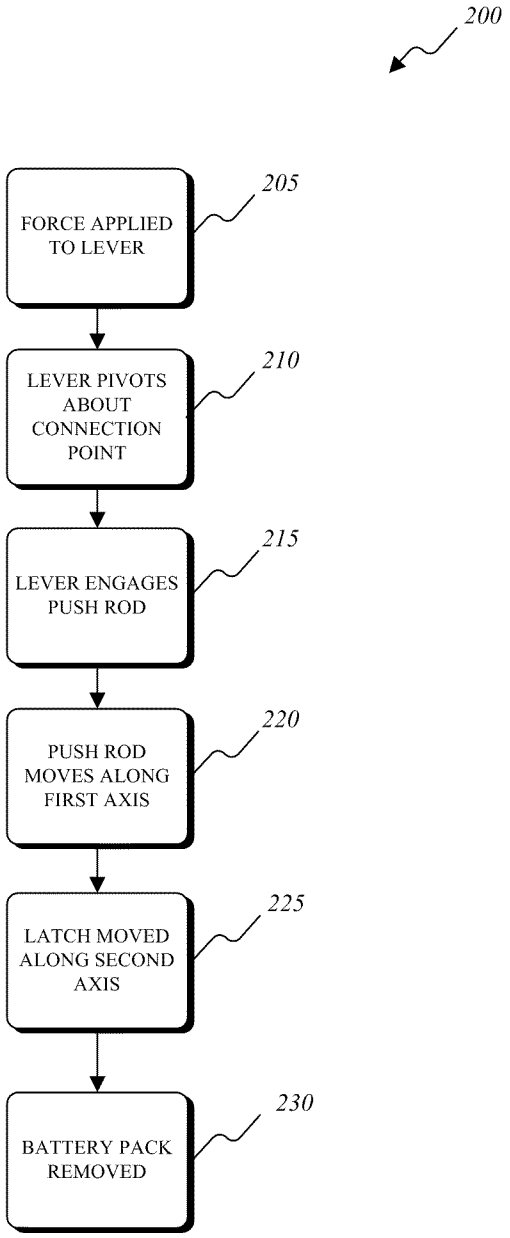

200
FORCE APPLIED TO LEVER
205
LEVER PIVOTS ABOUT CONNECTION POINT
210
LEVER ENGAGES PUSH ROD
215
PUSH ROD MOVES ALONG FIRST AXIS
220
LATCH MOVED ALONG SECOND AXIS
225
BATTERY PACK REMOVED
230

FIG. 13

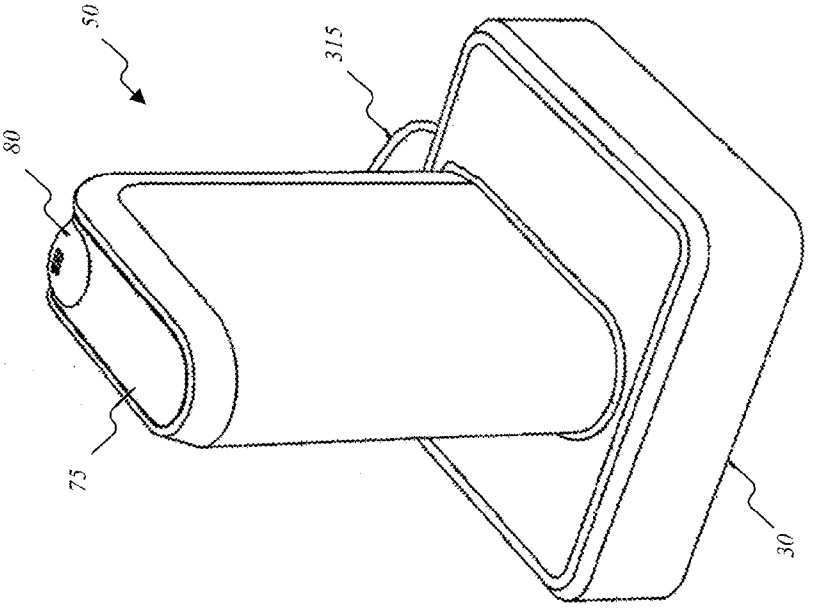
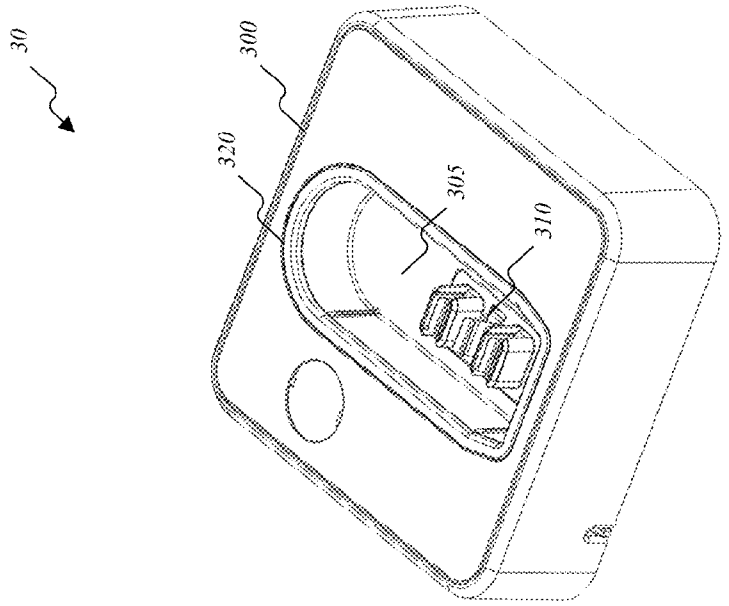


FIG. 12



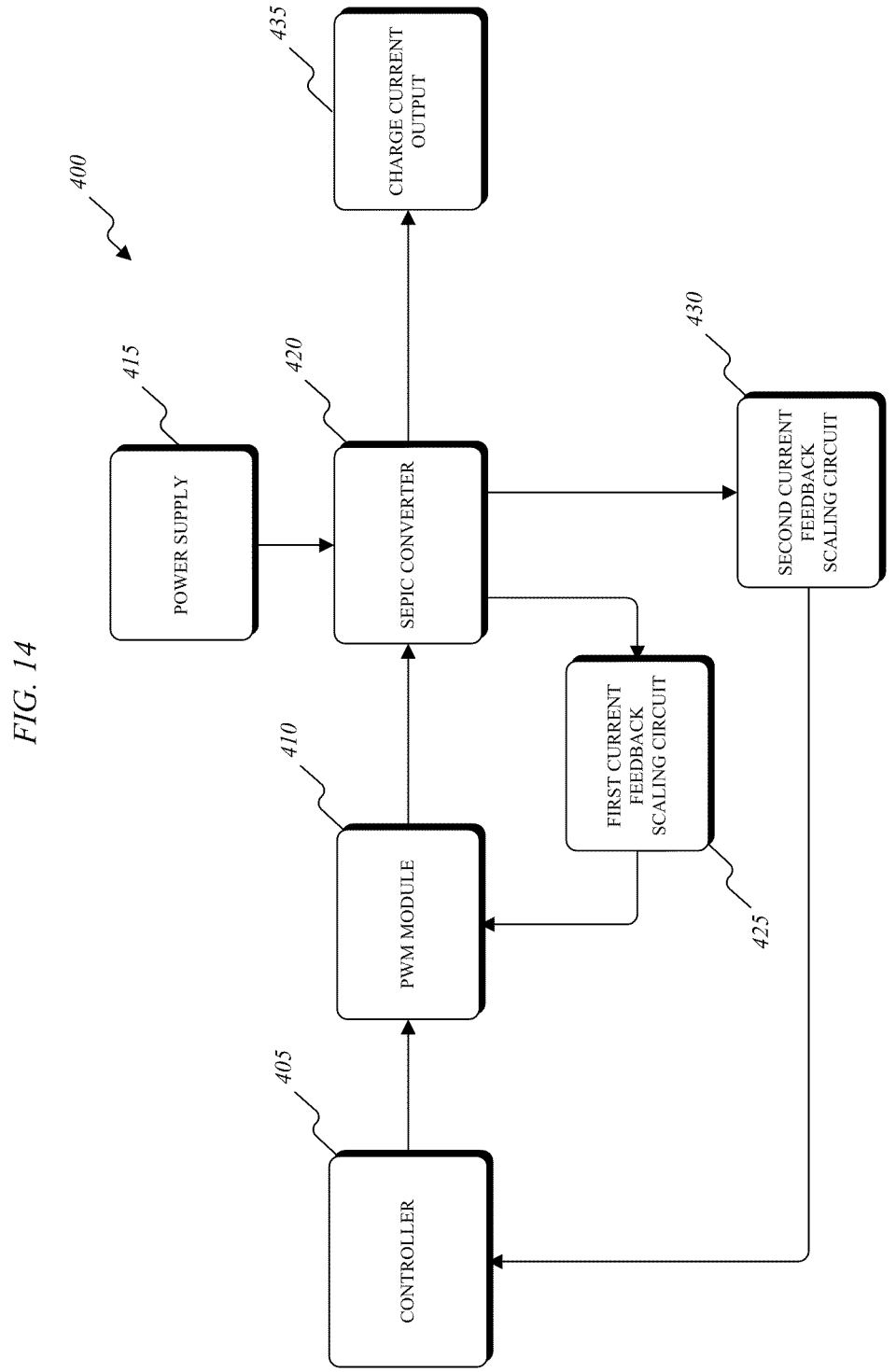

400
405
CONTROLLER
410
PWM MODULE
415
POWER SUPPLY
420
SEPIC CONVERTER
425
FIRST CURRENT FEEDBACK SCALING CIRCUIT
430
SECOND CURRENT FEEDBACK SCALING CIRCUIT
435
CHARGE CURRENT OUTPUT

FIG. 14

FIG. 15

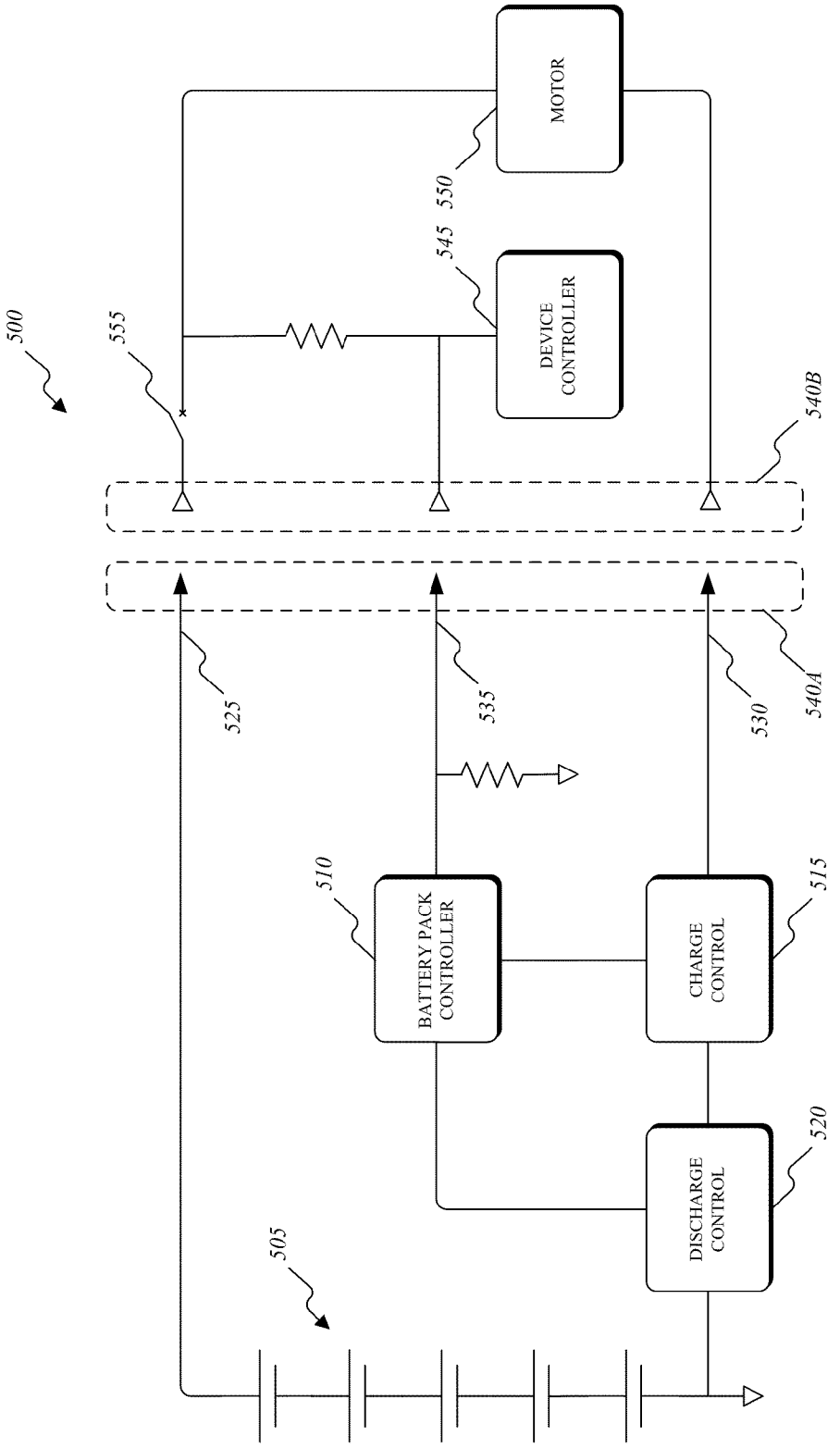

500
555
MOTOR
550
545
DEVICE CONTROLLER
540B
540A
525
535
530
510
BATTERY PACK CONTROLLER
CHARGE CONTROL
515
DISCHARGE CONTROL
520
505

FIG. 16

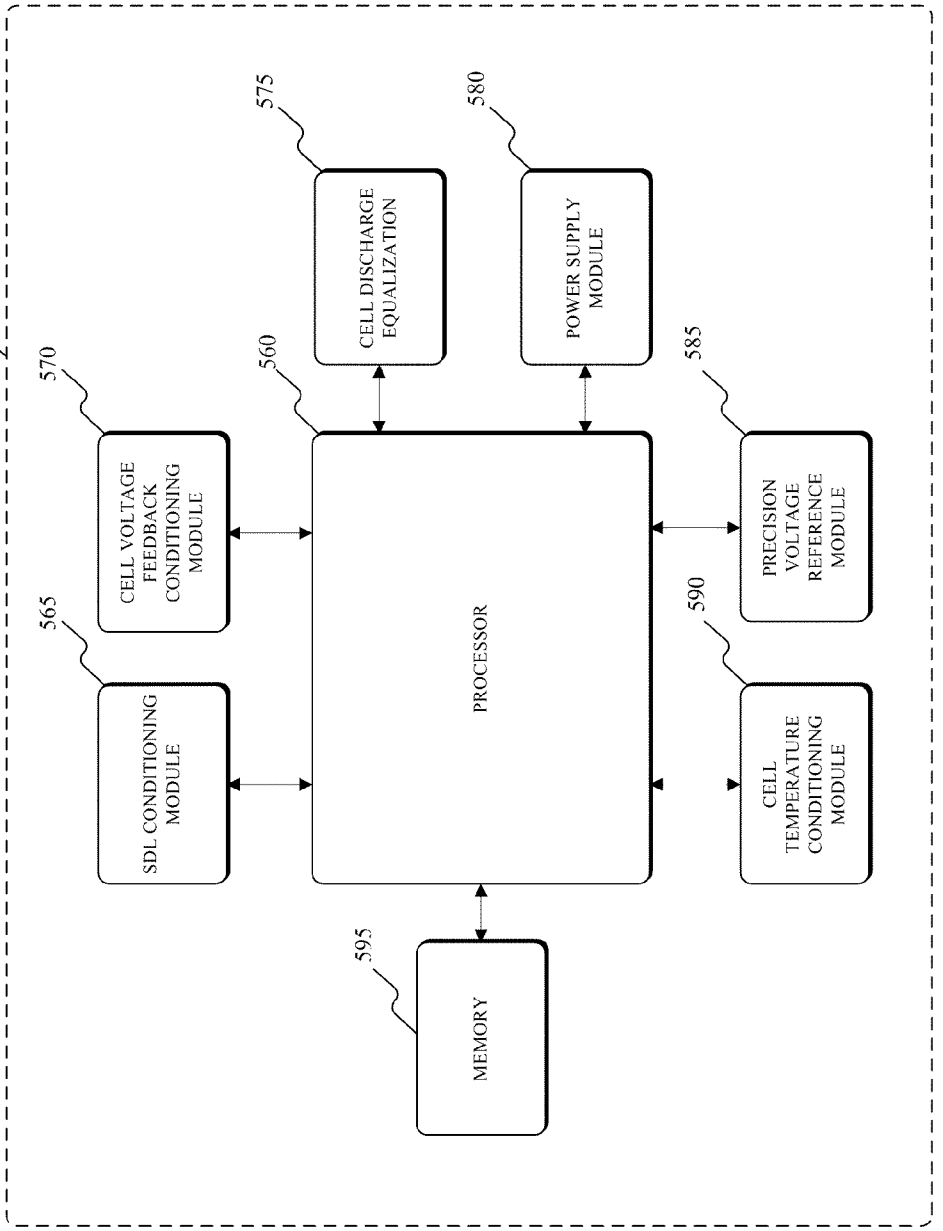

510
575
CELL DISCHARGE EQUALIZATION
580
POWER SUPPLY MODULE
570
CELL VOLTAGE FEEDBACK CONDITIONING MODULE
560
PROCESSOR
585
PRECISION VOLTAGE REFERENCE MODULE
565
SDL CONDITIONING MODULE
590
CELL TEMPERATURE CONDITIONING MODULE
595
MEMORY

FIG. 17

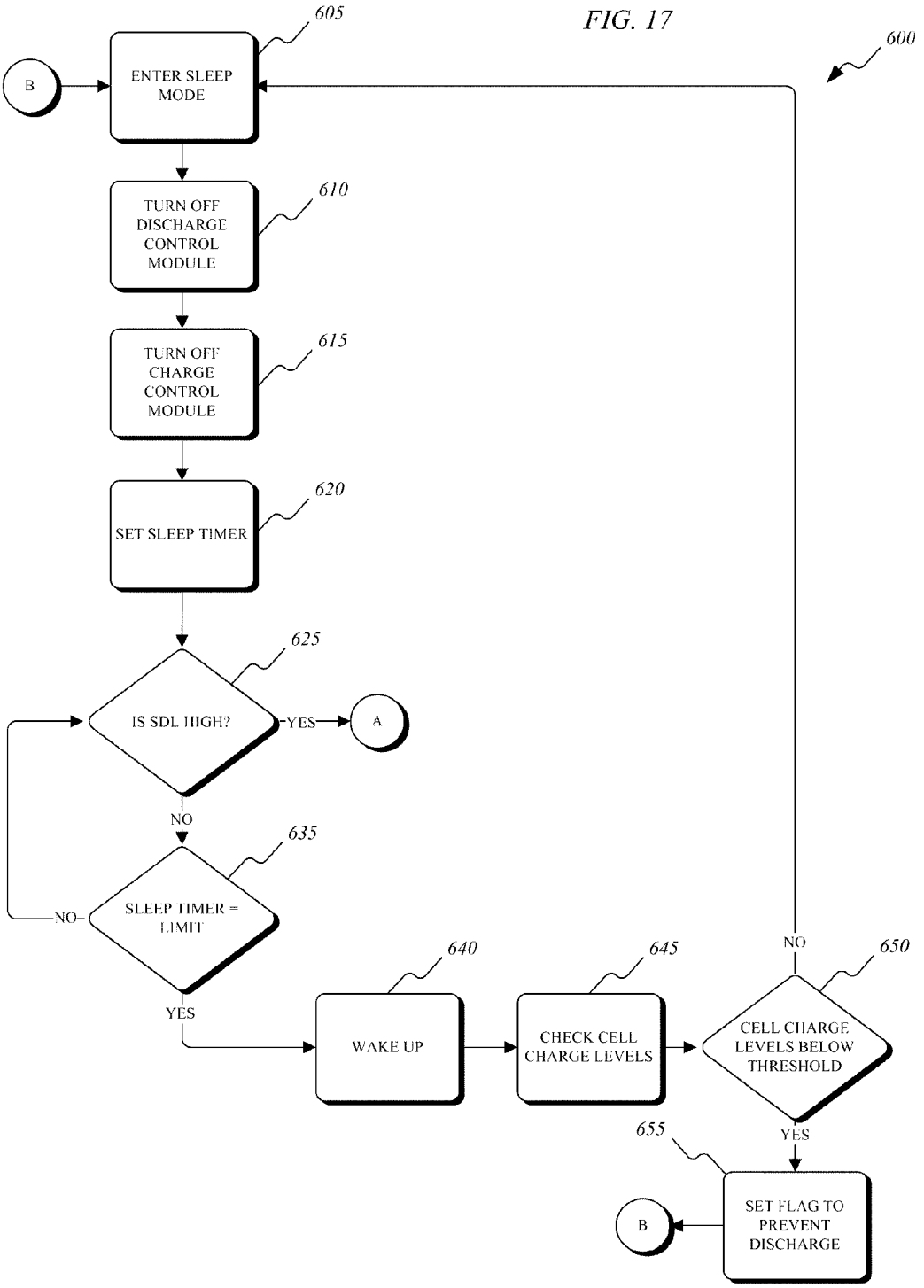

600
605
ENTER SLEEP MODE
B
610
TURN OFF DISCHARGE CONTROL MODULE
615
TURN OFF CHARGE CONTROL MODULE
620
SET SLEEP TIMER
625
IS SDL HIGH?
YES
A
NO
635
SLEEP TIMER = LIMIT
NO
YES
640
WAKE UP
645
CHECK CELL CHARGE LEVELS
650
CELL CHARGE LEVELS BELOW THRESHOLD
NO
YES
655
SET FLAG TO PREVENT DISCHARGE
B

FIG. 18

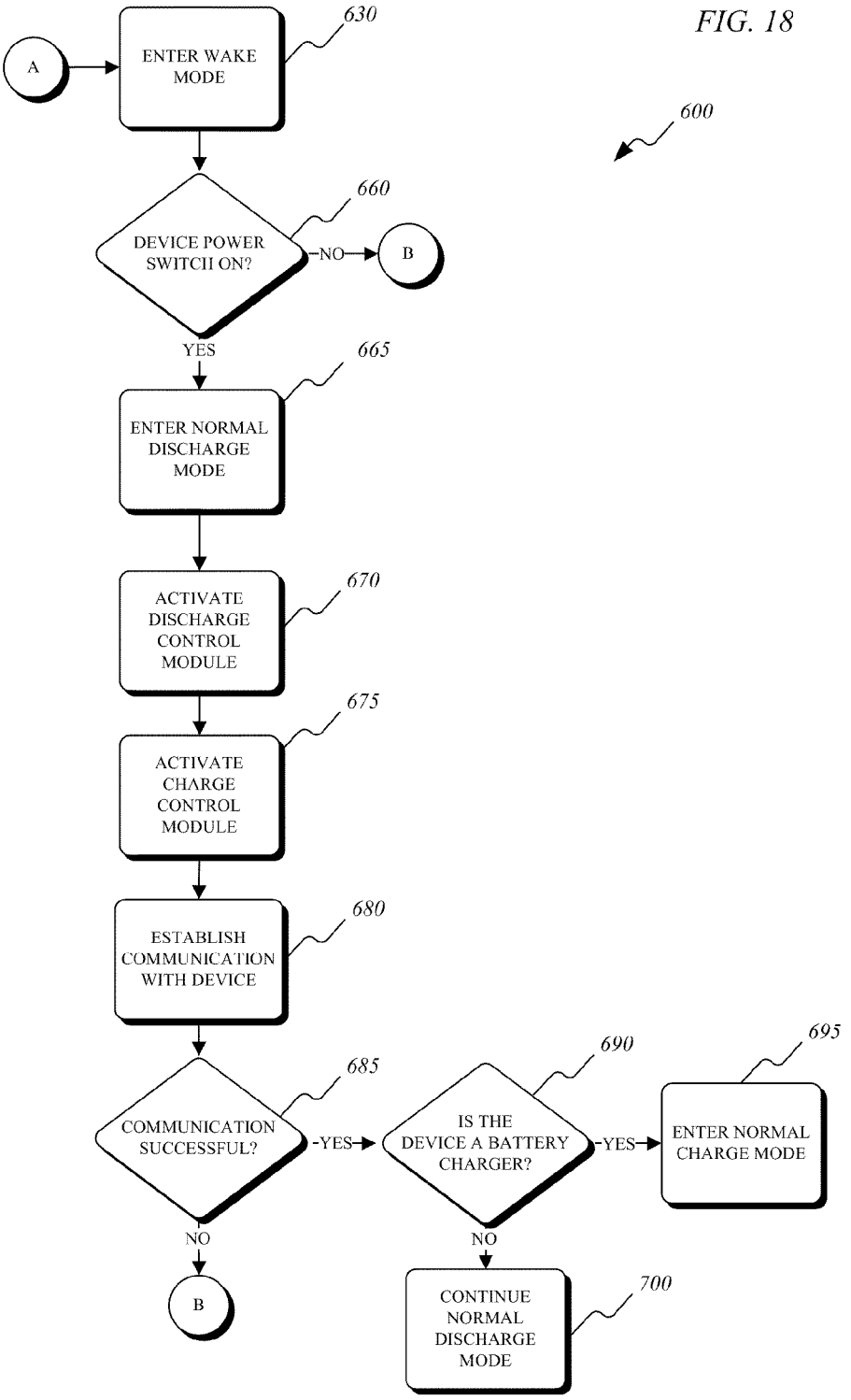
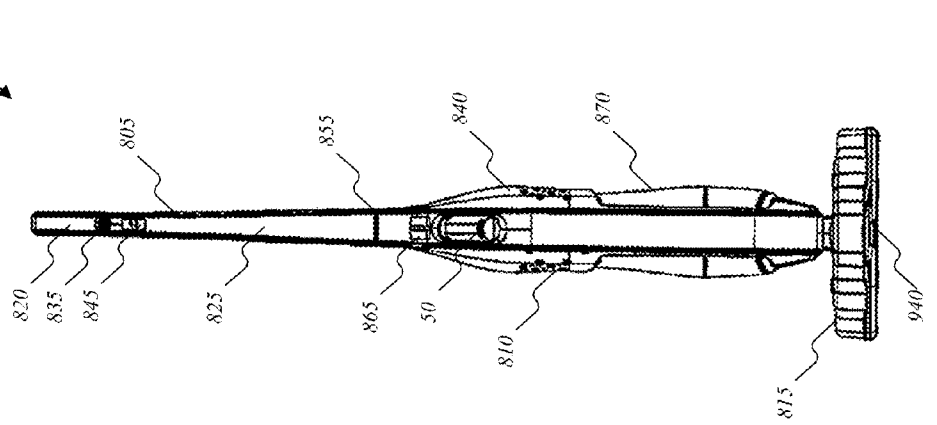

600
A
ENTER WAKE MODE
630
DEVICE POWER SWITCII ON?
660
NO
B
YES
ENTER NORMAL DISCHARGE MODE
665
ACTIVATE DISCHARGE CONTROL MODULE
670
ACTIVATE CHARGE CONTROL MODULE
675
ESTABLISH COMMUNICATION WITH DEVICE
680
COMMUNICATION SUCCESSFUL?
685
YES
IS THE DEVICE A BATTERY CHARGER?
690
YES
ENTER NORMAL CHARGE MODE
695
NO
B
NO
CONTINUE NORMAL DISCHARGE MODE
700

FIG. 20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805
855
840
870
820
835
845
825
865
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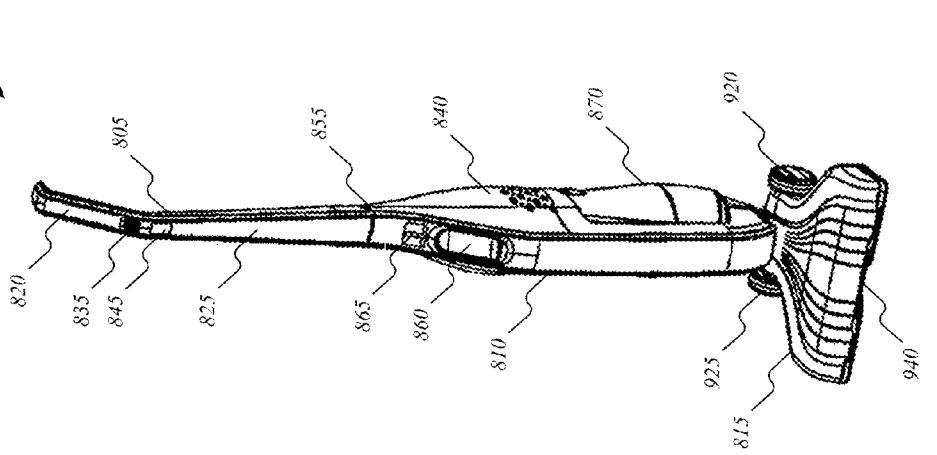
810
815
940

FIG. 19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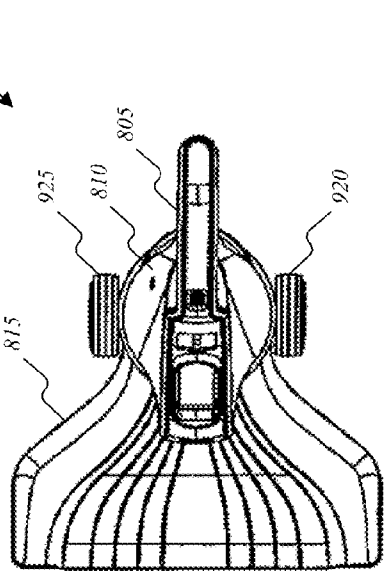


FIG. 22

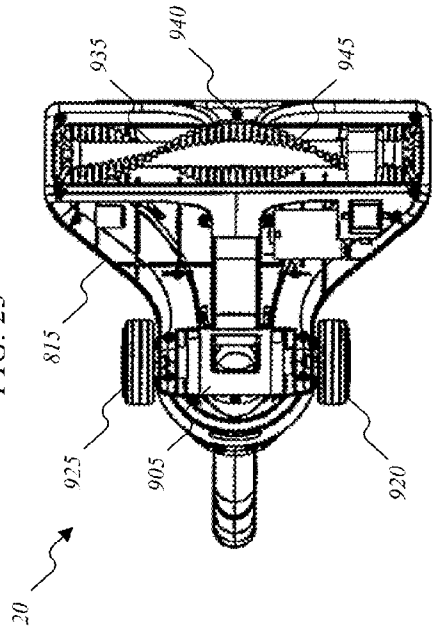


FIG. 23

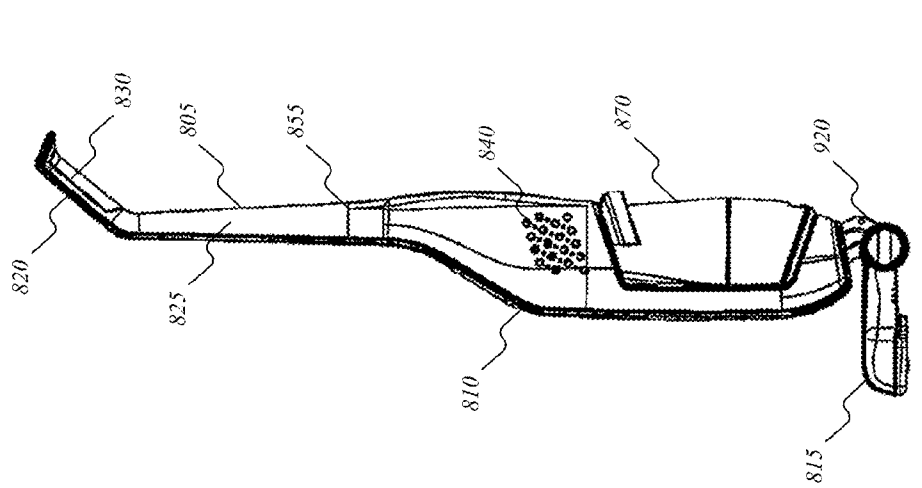


FIG. 21

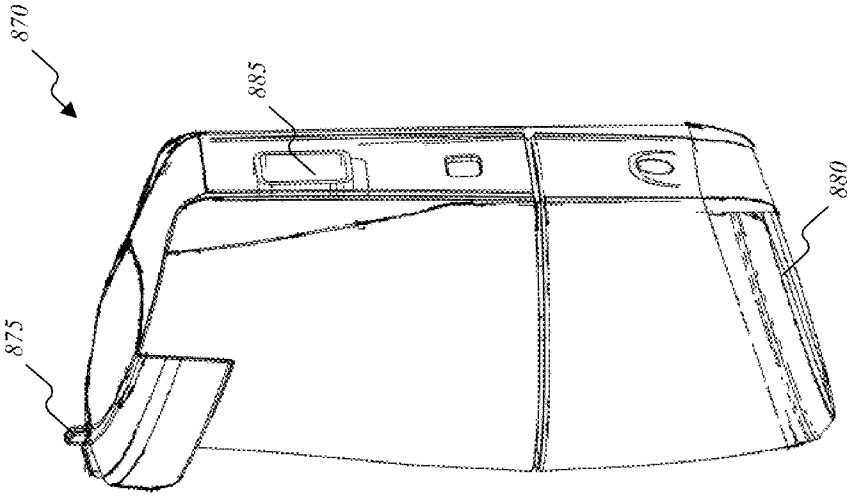


FIG. 25

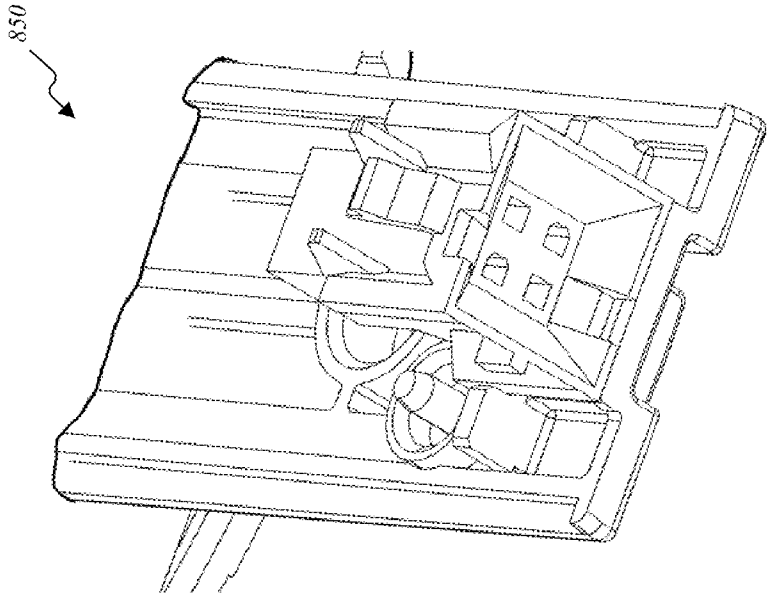


FIG. 24

FIG. 26

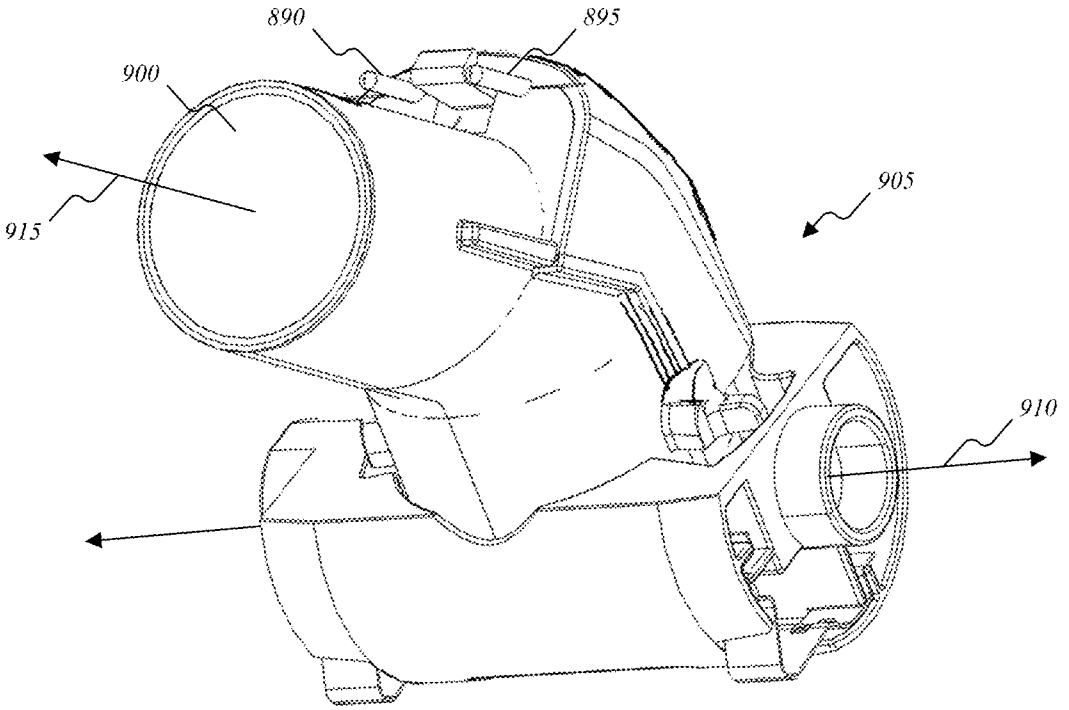


FIG. 27

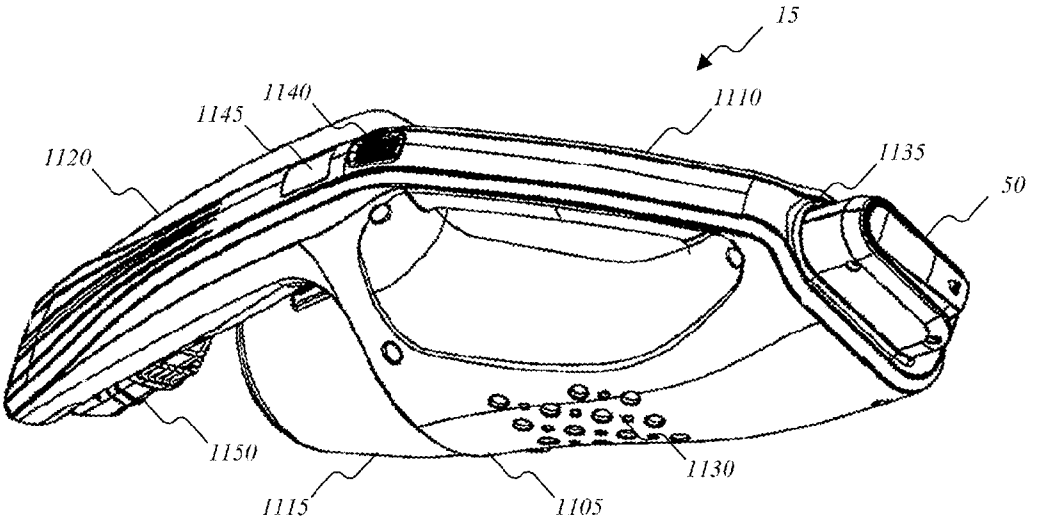

15
1140
1145
1110
1120
1135
50
1150
1130
1115
1105

FIG. 28

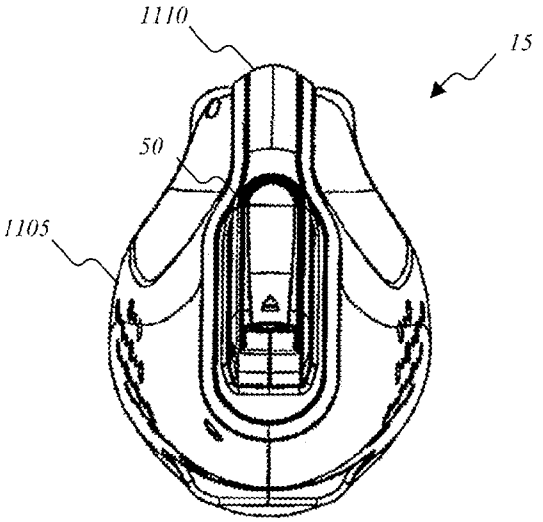

1110
15
50
1105

FIG. 29

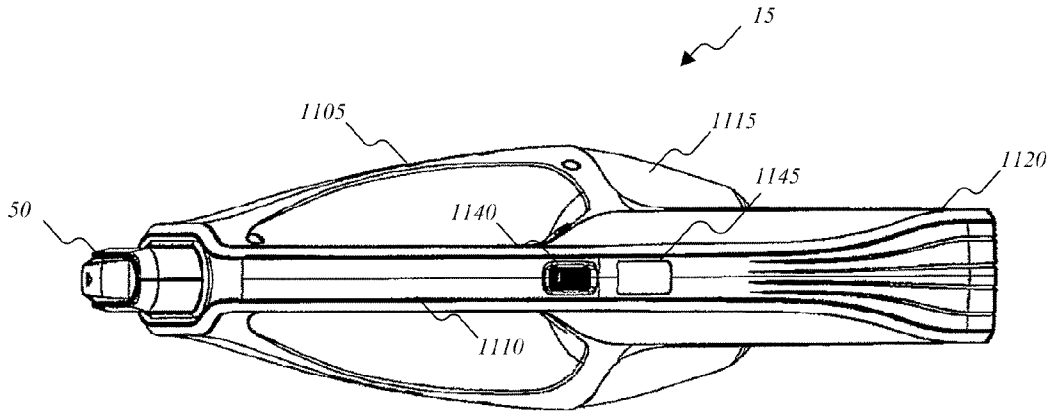

15
1105
1115
1120
1145
50
1140
1110

FIG. 30

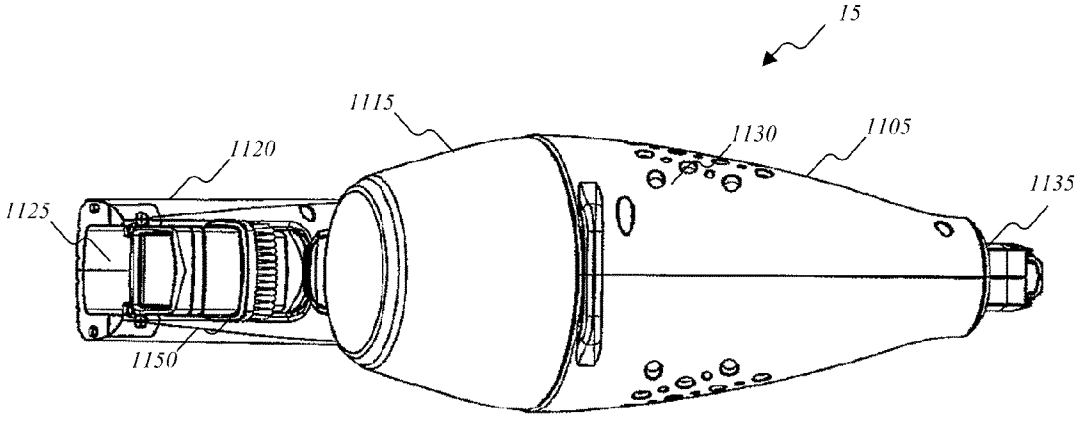

15
1115
1130
1105
1120
1135
1125
1150

FIG. 31

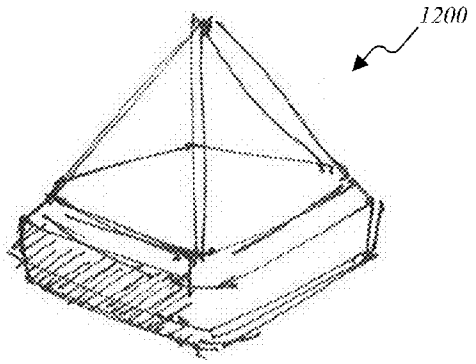


FIG. 32

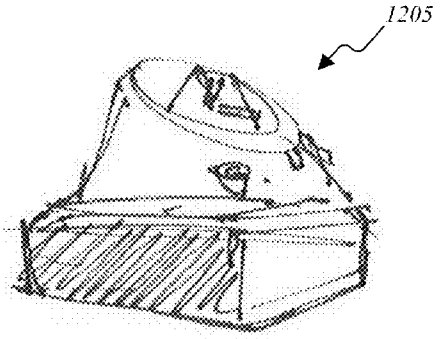


FIG. 33

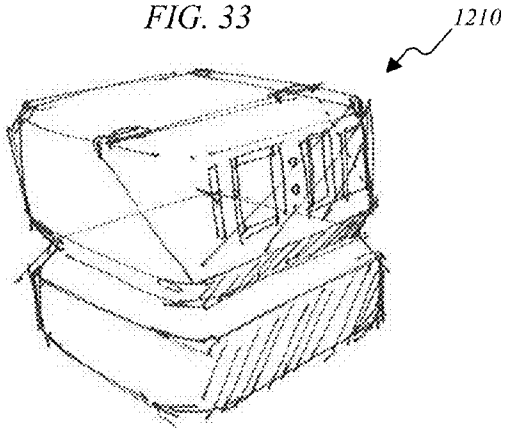


FIG. 34

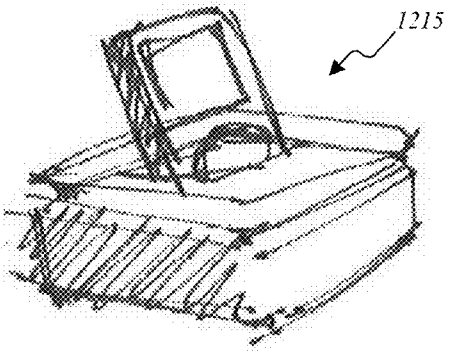


FIG. 35

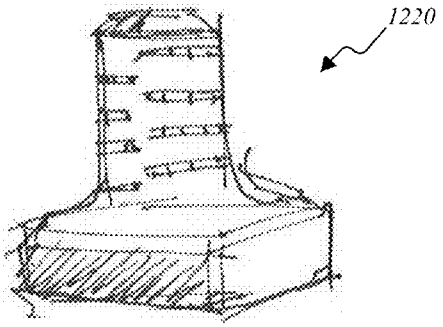
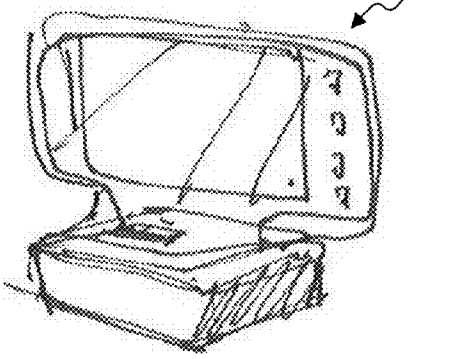


FIG. 36



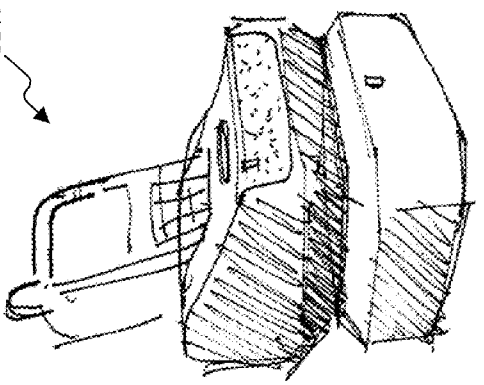


FIG. 39

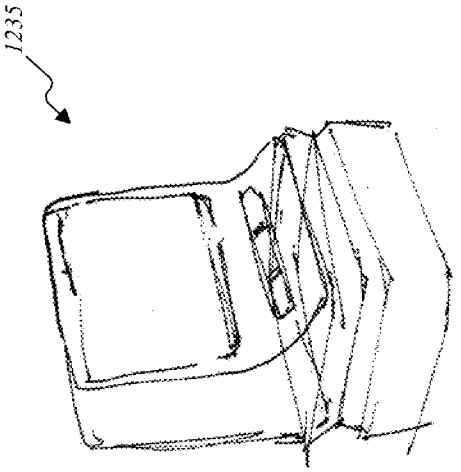


FIG. 38

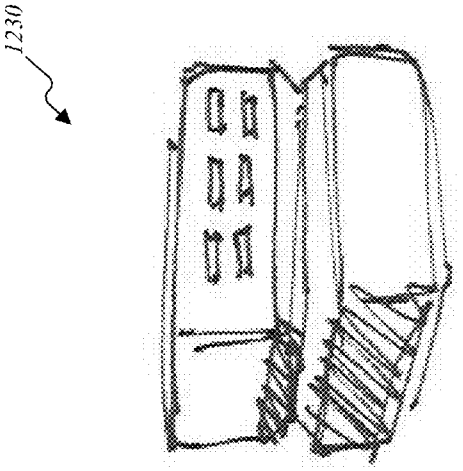


FIG. 37

BATTERY POWERED CORDLESS CLEANING SYSTEM

RELATED APPLICATIONS

This application is a continuation-in-part of previously-filed co-pending U.S. patent application Ser. No. 12/405,033, filed Mar. 16, 2009, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/036,720, filed Mar. 14, 2008, the entire contents of both of which are hereby incorporated by reference.

This application is also a continuation-in-part of U.S. patent application Ser. No. 29/326,368, filed Oct. 16, 2008, U.S. patent application Ser. No. 29/326,362, filed Oct. 16, 2008, and U.S. patent application Ser. No. 29/326,364, filed Oct. 16, 2008, the entire contents of all of which are hereby incorporated by reference.

This application also claims the benefit of previously-filed co-pending U.S. Provisional Patent Application Ser. No. 61/105,891, filed Oct. 16, 2008, U.S. Provisional Patent Application Ser. No. 61/105,899, filed Oct. 16, 2008, and U.S. Provisional Patent Application Ser. No. 61/105,896, filed Oct. 16, 2008, the entire contents of all of which are hereby incorporated by reference.

BACKGROUND

Consumer devices, such as suction force cleaners having both a suction motor and impeller or fan assembly (e.g., vacuum cleaners), have been limited almost exclusively to corded, AC powered devices. The power required to operate such devices is prohibitive to the development of a cordless vacuum cleaner that is able to provide portability, functionality, and adequate suction force. Attempts have been made to incorporate battery packs into vacuum cleaners. Although some of these attempts have succeeded in reducing vacuum cleaners' dependence on AC power, they have been unable to provide a solution that is adequate among multiple types of devices.

SUMMARY

Cleaning systems include a wide range of products designed to meet a wide variety of cleaning needs, and cleaning often requires the use of multiple devices to sufficiently clean a room or space. Large and small cleaning devices alike suffer from a lack of portability and operational congruence. For example, the multiple devices used for cleaning often include an upright suction force cleaner for cleaning large surface areas with a significant amount of debris and a smaller, hand-held cleaning device for cleaning smaller or confined areas. As another example, a canister vacuum is used in combination with an upright cleaning device or a hand-held vacuum. No matter the combination of devices being used, the efficiency, portability, and compatibility associated with using multiple devices is hindered by, among other things, the different power requirements of each device. For example, a hand vacuum, which is typically a battery powered device, requires its own charger or replaceable batteries, and an upright vacuum, which is typically a corded device, requires a user to be within power cord-range of a power outlet.

Embodiments of the invention provide a cordless cleaning system that includes devices such as a stick vacuum, a lightweight upright vacuum, a hand-held vacuum, a carpet-cleaner, a canister vacuum, and the like. Each of the devices is capable of being powered by a single battery pack which is interchangeable among the devices. For example, the battery pack is initially inserted into the stick vacuum, and is then removed and inserted into the hand-held vacuum. The battery pack includes a combination of hardware and software for identifying and communicating with each of the devices to ensure that each of the devices receives the power necessary to ensure optimal performance. The battery pack also includes additional control electronics which maximize the charge-life of the battery pack, allow charging parameters and characteristics to be modified, and ensure an accurate charge determination for both the battery pack as a whole and the individual cells within the battery pack.

In one embodiment, the battery pack is configured to enter a "sleep" mode when not inserted in a battery charger or other valid device (e.g., during a storage period). When in the sleep mode, power consumption of the battery pack is minimized to maintain cell charge. During the sleep mode, the battery pack removes power from its power terminals, and a battery pack control circuit enters a low or reduced power mode to prolong the life of the battery. The battery pack is also configured to enter a "wake" mode when the battery pack is inserted into an electrical device, and a voltage (e.g., a logical high voltage) is applied to a serial communication terminal of the battery pack. If no voltage is applied to the serial communication terminal, the battery pack is configured to wake up from the sleep mode once every 1-2 hours to perform a voltage level check and a battery cell temperature check.

In another embodiment, the battery pack is configured to communicate with devices (e.g., a battery charger, a configuration device, etc.) to adjust or change the charge and/or discharge parameters of the battery pack. Additionally or alternatively, a battery pack controller is configured to store cell-specific operating parameters in a memory, and is capable of adjusting or changing the operating parameters according to information received from the devices.

In yet another embodiment, the battery pack is configured to communicate with a device (e.g., a battery charger, a cleaning device, etc.) which includes a fuel gauge that displays the remaining battery charge capacity of the battery pack. The battery pack stores cell-specific operating parameters in a memory and provides information to the device's fuel gauge that accurately represents the remaining battery charge capacity of the battery pack. The information is based on the operating parameters stored in memory including, among other things, discharge currents and cell voltage threshold values.

Additionally, the battery pack is operable to provide power to any of a plurality of additional devices. For example, the battery pack is capable of providing power to any number of devices having different voltage and current requirements, such as power tools, test and measurement equipment, outdoor power equipment, and vehicles. Power tools include, for example, drills, circular saws, jig saws, band saws, reciprocating saws, screw drivers, angle grinders, straight grinders, hammers, impact wrenches, angle drills, inspection cameras, and the like. Test and measurement equipment includes digital multimeters, clamp meters, fork meters, wall scanners, IR temperature guns, and the like. Outdoor power equipment includes blowers, chain saws, edgers, hedge trimmers, lawn mowers, trimmers, and the like. The battery pack is also capable of providing power to devices such as a night or mood light, a kitchen timer, a clock, an audio storage device dock, an air ionizer, an air freshener, a fan, an LCD screen, a USB charging station, an indoor weather station, a flashlight, a radio, a DVD or Blu-ray player, an mp3 player, and a mobile phone charger or speakerphone.

In one embodiment, the invention provides a cordless cleaning system that includes a rechargeable battery pack, a

first cordless cleaning device, and a second cordless cleaning device. The rechargeable battery pack includes a housing and at least two cells within the housing. The first cordless cleaning device and the second cordless cleaning device are operable to removably receive and be powered by the battery pack. The first device is a first type of cleaning device, the second device is a second type of cleaning device, and the first type of cleaning device is different than the second type of cleaning device. At least one of the first device and the second device has an upright working position.

In another embodiment, the invention provides a cordless vacuum cleaner. The vacuum cleaner includes a nozzle base portion, a body portion, a vacuum motor, a brush roll motor, and a fuel gauge. The nozzle base portion includes a suction inlet, and the body portion is operable to receive a lithium-based battery pack that is removably coupled to the vacuum cleaner. The body portion is also pivotable relative to the nozzle base portion. The vacuum motor is powered by the battery pack and is configured to provide a suction force at the suction inlet. The brush roll motor is powered by the battery pack and is configured to provide rotational movement to a brush roll. The vacuum cleaner is configured to operate in a first mode in which the vacuum motor is operable, and a second mode in which the brush roll motor and the vacuum motor are operable. The fuel gauge is external to the battery pack and is positioned in at least one of the body portion and the nozzle base portion. The fuel gauge is configured to indicate a status of the battery pack.

In yet another embodiment, the invention provides a cordless vacuum cleaner. The vacuum cleaner includes a nozzle base portion, a body portion, a pivotable joint, a suction source, and a battery pack interface. The nozzle base portion includes a suction inlet, and the pivotable joint is coupled between the nozzle base portion and the body portion. The suction source provides a suction force at the suction inlet, and the battery pack interface is configured to receive a removable and rechargeable lithium-based battery pack. The source of suction is powered by the battery pack, and the body portion is pivotable relative to both a first axis and a second axis. The body portion is also supportable by the nozzle base portion in a vertical position without external support.

Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a cordless cleaning system according to an embodiment of the invention.

FIG. **2** is a perspective view of a battery pack according to an embodiment of the invention.

FIG. **3** is another perspective view of the battery pack of FIG. **2**.

FIG. **4** is a partial perspective view of the battery pack of FIG. **2**.

FIG. **5** is a side view of a lever according to an embodiment of the invention.

FIG. **6** is another side view of a lever according to an embodiment of the invention.

FIG. **7** is a side view of the battery pack of FIG. **2** with an external housing removed.

FIG. **8** is a perspective view of a latching mechanism according to an embodiment of the invention.

FIG. **9** is a perspective view of the battery pack of FIG. **2** with the external housing removed.

FIG. **10** is another perspective view of the battery pack of FIG. **2** with the external housing removed.

FIG. **11** shows a process for removing the battery pack of FIG. **2** from a device according to an embodiment of the invention.

FIG. **12** is a perspective view of a battery charger according to an embodiment of the invention.

FIG. **13** is a perspective view of the battery pack of FIG. **2** inserted into the battery charger of FIG. **12**.

FIG. **14** illustrates a charging circuit for a battery charger according to an embodiment of the invention.

FIG. **15** illustrates a control circuit and an interface between a battery pack and a device according to an embodiment of the invention.

FIG. **16** illustrates a battery pack controller according to an embodiment of the invention.

FIGS. **17** and **18** show a process for switching a battery pack between a "sleep" mode and a "wake" mode.

FIG. **19** is a perspective view of a cleaning device according to an embodiment of the invention.

FIG. **20** is a front view of the cleaning device of FIG. **19**.

FIG. **21** is a side view of the cleaning device of FIG. **19**.

FIG. **22** is a top view of the cleaning device of FIG. **19**.

FIG. **23** is a bottom view of the cleaning device of FIG. **19**.

FIG. **24** is a perspective view of an interface between a handle portion and a body portion of the cleaning device of FIG. **19** according to an embodiment of the invention.

FIG. **25** is a perspective view of a refuse chamber for the cleaning device of FIG. **19** according to an embodiment of the invention.

FIG. **26** is a perspective view of an interface between a base portion and a body portion of the cleaning device of FIG. **19** according to an embodiment of the invention.

FIG. **27** is a perspective view of a cleaning device according to another embodiment of the invention.

FIG. **28** is a rear view of the cleaning device of FIG. **27**.

FIG. **29** is a top view of the cleaning device of FIG. **27**.

FIG. **30** is a bottom view of the cleaning device of FIG. **27**.

FIGS. **31-39** illustrate devices coupled to the battery charger of FIG. **12** according to embodiments of the invention.

DETAILED DESCRIPTION

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

Embodiments of the invention described herein relate to a cordless, battery-powered system of electronic devices, such as a system of cleaning products. The system of cleaning products includes devices such as upright vacuums (e.g., a stick-type vacuum, a lightweight upright vacuum, etc.), a hand-held vacuum, a carpet-cleaner, a canister vacuum, a wet/dry floor cleaner, and the like. Each of the devices is powered by a battery pack which is interchangeable among the devices. The battery pack includes a combination of hardware and software for connecting to, identifying, and communicating with each of the devices to ensure that each of the devices receives the power necessary to ensure optimal performance. For example, the battery pack includes a latch and a rod for removably securing the battery pack to the devices. The battery pack also includes control electronics which maximize the charge-life of the battery pack by operating the battery pack in a "sleep" mode, allow charging parameters

and characteristics to be modified, and ensure an accurate battery pack charge determination.

FIG. **1** illustrates a cordless cleaning system **10** that includes a hand-held vacuum **15**, a stick-type vacuum **20**, a bagless upright vacuum **25**, a battery charger **30**, a bagged upright vacuum **35**, a carpet cleaner **40**, and a canister vacuum **45**. Each of the devices **15-45** is connectable to and powered by a battery pack **50**. The battery pack **50** has, for example, a nickel-metal hydride ("NiMH"), nickel-cadmium ("NiCd"), lithium-cobalt ("Li—Co"), lithium-manganese ("Li—Mn"), Li—Mn spinel, or other suitable lithium or lithium-based chemistry. The battery pack **50** has a nominal voltage rating of 4V, 8V, 12V, 16V, 18V, 20V, 24V, 36V, 48V, etc., or any voltage rating therebetween or greater than 48V. Battery cells within the battery pack **50** have capacity ratings of, for example, 1.2 Ah, 1.3 Ah, 1.4 Ah, 2.0 Ah, 2.4 Ah, 2.6 Ah, 3.0 Ah, etc. The individual cell capacity ratings are combined to produce a total battery pack capacity rating, which is based both on the capacity ratings of the individual cells and the number of cells in the battery pack **50**. In some embodiments, the individual battery cells have energy densities of 0.348 Wh/cm^3, although other energy densities are used in other embodiments. The battery pack **50** is able to provide an overall energy density of, for example, at least 0.084 Wh/cm^3.

FIGS. **2-10** illustrate the battery pack **50** in greater detail. The battery pack **50** includes a housing **55** formed of a first half or shell **60** and a second half or shell **65**. The first and second shells **60** and **65** are coupled to one another using, for example, screws **70** or other suitable fastening devices or materials. A lever **75** is pivotally mounted to the housing **55**, and enables the removal of the battery pack **50** from each of the devices in the cordless cleaning system **10**. A first end **80** of the lever **75** is pulled to unlatch or to eject the battery pack **50** from a device. In some embodiments, the first end **80** is formed as a raised portion adjacent to a recess **85**. The raised portion of the first end **80** and the recess **85** are sized to receive, for example, a user's finger or another object to pivot the lever **75**.

The lever **75** is pivotally mounted to the housing **55**. A push rod **90** (FIG. **4**) is movably mounted to the housing **55**, and is configured to be axially moved by the pivoting motion of the lever **75**. A latch **95** is extendable, movably mounted to the housing **55**, and configured to be moved from a first position (e.g., a latched position) to a second position (e.g., an unlatched position) by the movement of the push rod **90**. While in the latched position, the latch **95** securely couples the battery pack **50** to a device. The movement of the latch **95** from the first position to the second position allows the battery pack **50** to be removed from a device. In the illustrated embodiments, a single latch is provided. In other embodiments, additional latches are provided within a battery pack.

As illustrated in FIGS. **5** and **6**, the lever **75** pivots about a connection point **100**. As the first end **80** of the lever **75** is lifted, a second end **105** of the lever **75** is rotated downward and brought into contact with the push rod **90**. The pivotal movement of the lever **75** about the connection point **100** is limited to an angle, A, of between, for example, zero and approximately 90 degrees. In some embodiments, the pivotal movement is between approximately zero degrees and approximately 45 degrees. In response to contact from the lever **75**, the push rod **90** is moved downward through an aperture **110** (FIG. **3**). In some embodiments, the lever **75** also includes legs **115** which extend from the first end **80**, and work in conjunction with the housing **55** to limit the pivotal movement of the lever **75**.

As shown in FIGS. **3** and **4**, electrical connections to the battery pack **50** are made through an interface **120**, which is slightly recessed within the housing **55**. Electrical connectors **125** and **130** are located on a bottom side **135** of the housing **55** and are adjacent to a supporting structure, which protects the electrical connectors **125** and **130** within the interface **120**.

FIGS. **7-10** illustrate the battery pack **50** with the housing **55** removed. The battery pack **50** includes one or more battery cells **140** positioned within the housing **55**. The push rod **90** is movable between a first position (e.g., a retracted position) and a second position (e.g., a protruded position). While in the retracted position, the push rod **90** is retracted within the housing **55**. While in the protruded position, the push rod **90** extends from the housing **55** through the aperture **110**. When the push rod **90** is extended through the aperture **110**, the force of the push rod **90** extending through the aperture **110** assists in the removal of the battery pack **50** from a device.

A biasing element, such as a spring **145**, biases the push rod **90** toward the retracted position. When the first end **80** of the lever **75** is pulled, the push rod **90** is driven downward against the biasing force of the spring **145** to move the latch **95** from the latched position to the unlatched position. When the lever **75** is moved through a sufficient angular distance, the latch **95** is moved from the latched position to the unlatched position, and the push rod **90** is moved from the retracted position to the protruded position.

The movement of the push rod **90** occurs along a first axis **150**, and movement of the latch **95** between the latched position and the unlatched position occurs along a second axis **155**. In some embodiments, the second axis **155** is oriented approximately normal to the first axis **150**. The push rod **90** and the latch **95** are then connected to, coupled to, or in contact with one another in a manner such that a movement of the push rod **90** along the first axis **150** is translated to a movement of the latch **95** along the second axis **155**. In one embodiment, the push rod **90** includes a tapered portion **160** which engages a tapered portion of the latch **95** upon movement of the push rod **90**.

To secure the battery pack **50** to a device, the latch **95** is biased into the latched position by a biasing element, such as the spring **165**. The movement of the push rod **90** forces the latch **95** into the unlatched position by overcoming the biasing force from the biasing element **165**. For example, the push rod **90** causes the latch **95** to move into the unlatched position from the latched position when the push rod **90** is moved a sufficient distance (e.g., when the lever **75** is pivotally moved through a sufficient angular distance). Additionally or alternatively, inserting the battery pack **50** into a device forces the latch **95** against the biasing element **165** and into the unlatched position. The latch **95** returns to the latched position when the battery pack **50** is fully inserted into the device.

The battery cells **140** are electrically connected in series and are physically connected such that the cells **140** are parallel to one another and aligned in a single row. In other embodiments, one or more additional series-connected groups of battery cells are connected in parallel with the battery cells **140**. The interface **120** is also aligned with the cells **140** at the bottom side **135** of the housing **55** (e.g., a small end of the housing **55**). Such an arrangement of the battery cells **140** and the interface **120** allows the heat generated by the cells **140** to be evenly distributed across the battery pack **50**. The battery pack **50** is inserted into a recess of a device with the bottom side **135** of the housing **55** first, and in some embodiments, more than half of a volume of the battery pack **50** is inserted into the recess.

A process **200** for removing the battery pack **50** from a device is illustrated in FIG. **11**. The process **200** includes applying a force to the first end **80** of the lever **75** (step **205**).

The force applied to the lever **75** causes the lever **75** to pivot about a connection point **100** (step **210**) and the second end **105** to engage the push rod **90** (step **215**). The pivoting of the lever **75** is translated into a movement of the push rod **90** along the first axis **150** (step **220**) following engagement with the second end **105** of the lever **75**. The movement of the push rod **90** causes the latch **95** to move against the biasing force of the biasing element **165** and move from the latched position to the unlatched position along the second axis **155** (step **225**). Once in the unlatched position, the latch **95** allows the battery pack **50** to be removed from the device (step **230**).

As previously described, the battery pack **50** is configured to be coupled to any of a plurality of devices, such as the devices illustrated in the cleaning system **10** of FIG. **1**. The battery charger **30** is illustrated in FIG. **12** and includes a charging base **300** which receives the battery pack **50** in a recess **305**. Electrical connectors **310** connect the battery charger **30** to the battery pack **50**. FIG. **13** illustrates the battery pack **50** coupled to the battery charger **30**. The battery charger **30** receives power from, for example, an AC or a DC voltage source via a power cord **315**. The battery charger **30** converts the received power to a DC power level suitable for charging the battery pack **50**. In some embodiments, the battery pack **50** has a run-time to charge-time ratio such that a device being powered by the battery pack **50** is able to operate for at least four minutes for every one hour of charging. In other embodiments, different run-time to charge-time ratios are provided.

The battery charger also includes an LED indicator **320**. The LED indicator **320** provides information to a user related to the state of the battery charger **30** and the battery pack **50**. For example, if the LED indicator **320** flashes twice followed by a one second off period, the battery pack **50** is either too hot or too cold. If the LED indicator **320** flashes continuously, the battery charger **30** has detected an error condition, or there is internal component damage to the battery pack **50** or battery charger **30**. If the LED indicator **320** remains illuminated after a battery pack **50** is removed, the battery charger **30** either needs a reset, or there is internal component damage to the battery charger **30**. When the LED indicator **320** is continuously lit, the battery pack **50** is charging, and if the LED indicator **320** pulses as it gradually dims and brightens, the battery pack **50** is fully charged.

FIG. **14** illustrates a charging circuit **400** for the battery charger **30**. The circuit **400** includes a device controller **405**, a pulse-width-modulation ("PWM") module **410**, a power supply module **415**, a single ended primary inductor converter ("SEPIC") module **420**, a first current feedback scaling module **425**, a second current feedback scaling module **430**, and a charge output module **435**. The battery charger circuit also includes one or more LEDs for indicating the battery charger's status, as previously described. In other embodiments, other devices (e.g., vacuums) include features similar to those described below with respect to the battery charger.

The controller **405** includes, among other things, a processing unit (e.g., a microprocessor, etc.), memory, and a bus. The bus connects various controller components (such as the memory) to the processing unit. In one embodiment, the memory includes read-only memory ("ROM"), random access memory ("RAM"), electrically-erasable programmable read-only memory ("EEPROM"), or flash memory. The controller **405** also includes input/output interfaces and software that includes routines for transferring information between components within the controller **405**. In other embodiments, the controller **405** includes additional, fewer, or different components. The controller **405** is also configured to communicate with other components or subsystems within the battery charger **30** using a bus or other communication interface. In some embodiments, a microcontroller that includes a memory and a bus is used in place of the controller **405**.

The controller **405** is configured to generate a charge current demand signal. The controller **405** sends the charge current demand signal to the PWM module **410**, and the PWM module **410** generates a PWM signal based on the charge current demand signal. The PWM signal is sent from the PWM module **410** to a current source such as the SEPIC converter module **420**. The SEPIC converter module **420** is configured to provide a variable voltage and current source to charge the battery pack **50**. The SEPIC converter module **420** includes, among other things, an oscillator, a power FET configured as a switching element, and additional support circuits. The current provided by the SEPIC converter module **420** is based on an analog voltage derived from the charge current demand signal and a low pass filter network (not shown). The SEPIC converter module **420** also includes two over-voltage shutdown inputs. A first over-voltage shutdown input is controlled by the controller **405**, and a second over-voltage shutdown input is controlled by a comparator circuit that operates independently of the controller **405**. The SEPIC converter module **420** provides first and second signals representative of the battery charging current to the first and the second current feedback scaling modules **425** and **430**. Each of the first and second current feedback scaling modules **425** and **430** includes a single range of operation. No range selection signal is needed for the current feedback scaling modules **425** and **430** to properly provide feedback signals to the components of the battery charger **30**.

The first current feedback scaling module **425** provides a first feedback signal to the PWM module **410**. The PWM module **410** uses the first feedback signal to adjust the PWM signal to the SEPIC converter module **420** to provide a current that accurately corresponds to the charge current demand signal. The second current feedback scaling module **430** provides a second feedback signal to the controller **405**. The controller **405** uses the second feedback signal to verify that the current flowing to the battery pack corresponds to the charge current demand signal. In some embodiments, the controller **405** adjusts the charge current demand signal in response to the second feedback signal.

The battery charger **30** is configured to monitor its output voltage and output current. If the output current exceeds a predetermined output current limit, the battery charger **30** turns off the SEPIC converter module **420** to interrupt the output current from the power terminals. If the voltage exceeds a predetermined output voltage limit, the battery charger **30** turns off the SEPIC converter module **420** to remove voltage from the power terminals.

The power supply module **415** supplies a nominal 18V DC voltage to the battery charger **30**. The power supply module **415** is powered by mains power with nominal line voltages between, for example, 100V and 240V AC and frequencies of approximately 50-60 Hz. The power supply module **415** is also configured to supply lower voltages to operate circuits and components within the battery charger **30**.

FIG. **15** illustrates a control circuit **500** for a battery pack, such as the battery pack **50**. The control circuit **500** includes a cell assembly **505**, a battery pack controller **510**, a charge control module **515**, and a discharge control module **520**. The battery pack also includes a first power terminal **525**, a second power terminal **530**, a serial data line ("SDL") or communication terminal **535**, and a product interface **540**A. In other embodiments of the invention, the battery pack includes a plurality of additional power and/or communication termi-

nals (e.g., multiple positive terminals). In some embodiments, the battery pack is configured to provide discharge currents between 7 and 11 Amps and can accommodate in-rush currents of between 60 and 70 Amps. In other embodiments, the battery pack is configured to provide and accommodate different current ranges. The battery pack is configured to connect to a device that includes, for example, a battery pack interface **540**B, a device controller **545**, a motor **550**, and a power switch **555**.

As illustrated in FIG. **16**, the battery pack controller **510** includes a processor or processing unit (e.g., a microprocessor, etc.) **560**, a serial data line conditioning module **565**, a cell voltage feedback conditioning module **570**, a cell discharge equalization module **575**, a power supply module **580**, a precision voltage reference module **585**, a cell temperature conditioning module **590**, a memory **595**, and one or more busses for interconnecting the components and modules within the controller **510**. The busses connect the various modules and controller components to the processing unit **560**. In one embodiment, the memory **595** includes read-only memory ("ROM"), random access memory ("RAM"), electrically-erasable programmable read-only memory ("EEPROM"), or flash memory. The controller **510** also includes input/output interfaces and software that includes routines for transferring information between components within the controller **510**. In other embodiments, the controller **510** includes additional, fewer, or different components. The controller **510** is also configured to communicate with other components or subsystems within the battery pack using busses or another communication interface. Software included in the implementation of the battery pack is stored in the memory **595** of the controller **510**. The software includes, for example, firmware, one or more applications, program data, and other program modules. In some embodiments, a microcontroller that includes a memory and a bus is used in place of the controller **510**. Although the controller **510** is illustrated as including a plurality of additional modules, in other embodiments, one or more of the modules **565**-**595** are separate from and connected to the controller **510**. The power supply module **580** is configured to provide a regulated DC voltage to the battery pack.

The battery pack controller **510** is configured to communicate with a device (e.g., a battery charger, a vacuum, etc.), measure the voltage of each cell in a cell assembly, measure the discharge current of the pack, control a plurality of field-effect-transistor ("FET") switches, measure the temperature of the cell assembly, and monitor the number of charge or discharge cycles. The battery pack communicates with the device via the SDL **535**. The SDL is coupled to the serial data line conditioning module **565** to condition the data transmitted and received by the battery pack. Each device that is connectable to the battery pack is capable of interrupting the SDL connection to the battery pack to reduce leakage current experienced by the battery pack if the battery pack remains connected to the device for an extended period of time while in the sleep mode.

Executable instructions stored within the memory **595** of the controller **510** are configured to maintain a count (e.g., a 16-bit count) that represents the number of charge or discharge cycles experienced by the battery pack. Additionally or alternatively, the instructions are configured to maintain a first count and a second count (e.g., first and second 16-bit counts). A first count records charge cycles and the second count records discharge cycles. The charge/discharge counts are incremented each time the battery pack successfully enters a normal discharge or normal charge mode (described below). The counts are stored in the memory **595** of the battery pack controller **510**.

The battery pack controller **510** is also configured to store charge and/or discharge operating parameters, cell identification information, and current charge capacity information in the memory **595**. The battery pack provides the charge and/or discharge operating parameters to a battery charger, a configuration device, or a cleaning device. The operating parameters include, for example, a voltage rating of the battery pack, a manufacturer of the battery pack, a model number for each of the cells in the battery pack cell assembly, a voltage rating or measurement for each cell in the cell assembly, a cell temperature rating or measurement for each cell in the cell assembly, a data table for correlating cell voltage values with discharge current values, and the like. In other embodiments, more or different parameters are provided to the battery charger, configuration device, or cleaning device.

The battery pack uses the charge and/or discharge operating parameters to, among other things, provide a device fuel gauge with an accurate charge capacity estimation. The fuel gauge is universal in that it does not have to be modified or calibrated for a device's expected discharge current. As such, a fuel gauge within a device that requires **15**A of discharge current can also accurately display the charge capacity of a battery pack in a device that requires **5**A of discharge current. For example, when the battery pack is inserted into a device, the battery pack controller **510** is configured to communicate with the fuel gauge within the device via the SDL. The battery pack controller **510** includes a table that is used to correlate a cell voltage at a particular discharge current to a remaining charge capacity of the battery pack.

The battery pack continuously monitors and measures its discharge current to identify a portion of the table to use to determine the remaining charge capacity of the battery pack. The voltage of each cell within the battery pack is then measured. The lowest measured cell voltage is used as a pointer in the table. The battery pack uses the lowest battery cell voltage measurement and a discharge current measurement to determine an estimated battery capacity for the battery pack based on the identification and operating parameter information stored in memory. The battery pack controller **510** transfers the charge capacity information to the fuel gauge (e.g., to a fuel gauge controller or display device). For example, the estimated battery capacity is transmitted as a 2-bit code that has four possible capacity levels. In other embodiments of the invention, more bits can be used to increase the accuracy of the battery capacity estimation displayed on the fuel gauge.

The fuel gauge displays the charge capacity of the battery pack without having to perform calculations or measure voltages. In some embodiments, the fuel gauge includes three LEDs. When all three LEDs are in an illuminated state, the battery capacity is greater than or equal to 75%. When two LEDs are in an illuminated state, the battery capacity is greater than or equal to 50%. When one LED is in an illuminated state, the battery capacity is greater than or equal to 25%. If a single LED is blinking, the battery capacity is less than 25%. In other embodiments, more or fewer LEDs are used, and the LEDs display different battery capacity ranges. Devices that include a fuel gauge are also able to use the characteristics of the cells in the cell assembly to adjust the operation of the fuel gauge, such that the fuel gauge more accurately represents the charge capacity of the battery pack.

Additionally or alternatively, the devices are configured to communicate with the battery pack to adjust other operations based on the operating parameters of the battery pack and cells. For example, if the voltage of one of the battery cells

falls below a predetermined low voltage limit, the battery pack turns off the charge control module **515** and the discharge control module **520** to terminate the discharge current regardless of the logic level of the SDL or the presence of valid communication with the device controller **545**. In some embodiments, the device terminates operation, prohibits features, or reconfigures itself to operate at a different voltage based on the information from the battery pack.

Because the battery pack provides information to the device to which it is connected, the battery charger **30** can be used to charge a variety of different battery packs without requiring a user to specify the battery pack voltage. The battery charger **30** adjusts, for example, charging currents, charging voltages, and cut-off thresholds to accommodate manufacturer's specifications for each cell in the cell assembly. By adjusting charge and discharge parameters for each cell in the cell assembly, the life and performance of the battery pack can be improved and errors relating to incorrect charging and/or discharging parameters can be reduced or eliminated.

The cell voltage feedback conditioning module **570** is configured to attenuate and condition the voltages from each cell in the cell assembly **505** to a level that is within the measurement range of the battery pack controller **510**'s analog-to-digital converter ("ADC"). The cell voltage feedback conditioning module **570** is activated by the battery pack controller **510** when the voltage of a cell is being measured, and is turned off by the battery pack controller **510** when cell voltages are not being measured to prevent unnecessary cell discharge. The cell discharge equalization module **575** is configured to apply a nominally equal load to each cell in the cell assembly **505** to prevent an imbalance in battery cell discharge. The cell discharge equalization module **575** is turned on and off at the same time as the cell voltage feedback conditioning module **570**.

The precision voltage reference module **585** is configured to provide a precise reference voltage to the controller **510**'s ADC. The voltage reference is used by the ADC to measure signals within the battery pack. The precision voltage reference module **585** is activated by the battery pack controller **510** when the ADC is taking a measurement. The cell temperature conditioning module **590** is configured to measure the temperature of the cells in the cell assembly using, for example, a thermistor. In some embodiments, the thermistor is thermally coupled to the cells using a thermally conductive gel.

The charge control module **515** is configured to control when the cell assembly **505** is charged. The charge control module **515** includes at least one FET which is configured as a switch and is controlled by the battery pack controller **510**. If the FET is "on," the cell assembly **505** can be charged. If the FET is "off," the cell assembly **505** cannot be charged. The discharge control module **520** includes at least one FET configured as a switch to control current discharge from the cell assembly **505**. If the FET is "on," the cell assembly **505** can be discharged. If the FET is "off," the cell assembly **505** cannot be discharged. The discharge control module **520** is controlled by the battery pack controller **510**.

A process **600** for switching the battery pack between a "sleep" mode and a "wake" mode is illustrated in FIGS. **17** and **18**. In addition to being a low-power mode for the battery pack, the sleep mode also provides safety benefits to the battery pack and its users. For example, while in the sleep mode, the battery pack is unable to supply any significant amount of power to an external device or its power terminals (e.g., currents in the micro-ampere range). As such, the risk of, for example, short-circuited power terminals causing a fire or similar safety concern is eliminated or significantly reduced. The battery pack enters the sleep mode (step **605**) when it is not inserted in the battery charger or a cleaning device, as described below. During the sleep mode, the discharge control module **520** is turned off (step **610**) and the charge control module **515** is turned off (step **615**) to prevent the battery pack from sourcing any significant current between a positive terminal and a negative terminal of the battery pack. Turning off the charge control module **515** and the discharge control module **520** also removes the ground path for the battery cells contained within the battery pack and removes the voltage from the power terminals. Turning off the charge control module **515** and the discharge control module **520** also prevents the battery pack from supplying power to an external load, being charged by the battery charger **30**, or being short-circuited. With the ground path removed, no devices are able to communicate with the battery pack controller **510** because there is no common ground reference. In some embodiments, a small signal-level current can flow between the positive terminal and the SDL when the battery pack is in the sleep mode. A sleep timer is then set (step **620**). Hardware within the battery pack controller continuously monitors the SDL (step **625**). If a high logic level (e.g., a high TTL level) is applied to the SDL, the hardware interrupts the battery pack controller **510**, and the controller **510** enters the wake mode (step **630**) (FIG. **18**). Otherwise, the controller **510** remains in the sleep mode.

While in the sleep mode, the battery pack controller **510** is configured to compare the sleep timer to a limit (e.g., 60-120 minutes) (step **635**). The battery pack wakes up (step **640**) when the sleep timer is equal to the limit. The battery pack performs a cell voltage check (step **645**) to determine (step **650**) whether the battery pack's cell assembly charge level has fallen to a level or below a threshold that prohibits discharge. If the battery pack determines that one or more of its cells have fallen below the minimum allowable level, the battery pack sets a software flag to prevent discharge (step **655**) and the battery pack re-enters the sleep mode (step **605**). The battery pack removes the software flag after the battery pack has been connected to the battery charger **30**. If the cells have not fallen below the minimum allowable level, the battery pack is configured to re-enter the sleep mode (step **605**). In some embodiments, the battery pack is configured to disconnect a positive terminal of the cell assembly to remove voltage from the power terminals, and additional or different hardware is used to switch between the sleep and wake modes. In some embodiments, various steps described above are combined into a single step, or the steps are executed in a different order. For example, in one alternative embodiment, the sleep mode is entered when the sleep timer is set.

The wake mode and wake-up procedure described herein are interrupt-driven. As such, the battery pack enters the wake mode without having to wait for a predefined time period or for the battery pack controller **510** to poll the SDL. If the battery pack is connected to a device with its power switch turned on, the device connects the battery pack's SDL to the battery pack's positive power terminal via a resistor network, and the battery pack's SDL is pulled high (e.g., pulled to a logical high level). When the battery pack controller **510** determines that a high logic level is applied to the SDL, the battery pack enters the wake mode (step **630**). The battery pack controller **510** then debounces the SDL and verifies whether the battery pack is connected to a device with its power switch turned on (step **660**). The battery pack controller **510** debounces the SDL for a predetermined period of time (e.g., 60 ms) to ensure that the voltage at the SDL was not a result of a noise spike.

If the battery pack is not connected to a device or the device's power switch is not turned on, the battery pack re-enters the sleep mode (step **605**). If the battery pack controller **510** determines that the logic level present at the SDL is the result of a connection between the battery pack and a device with its power switch turned on, the battery pack enters a normal discharge mode ("NDM") (step **665**) and activates or turns on the discharge control module **520** (step **670**) and the charge control module **515** (step **675**). Activating the discharge control module **520** and the charge control module **515** provides a common ground reference between the battery pack and the device, and power to the positive and negative power terminals. Communication between the battery pack and the device is then able to begin. The battery pack is configured to establish communication (step **680**) with the device controller **545** via the SDL. The battery pack then determines whether communication has been established (step **685**). If communication is not established, the battery pack re-enters the sleep mode (step **605**). If communication is established, the battery determines whether the device is a battery charger (step **690**). If the device is a battery charger, the battery pack enters a normal charge mode ("NCM") (step **695**). If the device is not a battery charger, the battery pack continues to operate in the normal discharge mode (step **700**).

In other embodiments of the invention, the battery pack is configured to disconnect a positive terminal of the cell assembly **505** (e.g., turn off at least one FET) when the battery pack is in the sleep mode. When the battery pack is inserted into a device, the device connects the SDL to the battery pack's negative terminal to provide a logical low level to the SDL when the device power switch **555** is turned on. The SDL is connected to the negative terminal using a resistor network within the device. The battery pack is configured to communicate with the device and debounce the SDL as described above. If, after debouncing, the logic level of the SDL meets predetermined conditions for a low logic level, the battery pack controller **510** turns on the charge and discharge control modules to supply current to or receive current from the device.

The battery pack is also configured to transmit multi-byte messages to the device on the SDL. The device is configured to receive the messages on the SDL and respond with a message to the battery pack controller **510** related to, for example, the condition of the battery pack (e.g., charging mode, discharging mode, etc.). The battery pack controller **510** periodically polls the device controller **545** to verify presence and proper function. For example, the battery pack controller **510** sends five messages over the SDL during a period of one second to initiate communication with the device. If the battery pack controller **510** does not receive an expected response or a valid message from the device controller **545** during this time period, the battery pack controller **510** turns off the charge and discharge control modules **515** and **520**, and enters the sleep mode regardless of the logic level of the SDL. Turning off the charge and discharge control modules **515** and **520** removes the ground path for the cell assembly **505** to stop the supply of power to the device.

Additionally or alternatively, if the battery pack and the device fail to successfully maintain communication, the battery pack controller **510** turns off the charge and discharge control modules **515** and **520** and enters the sleep mode. For example, the battery pack controller sends a message to the device controller approximately once per second. If the battery pack controller does not receive a valid response to this message within a certain number of communication cycles (e.g., three communication cycles), the battery pack controller **510** turns off the charge and discharge control modules **515** and **520** and enters the sleep mode. In other embodiments, the battery pack is configured to disconnect the positive terminal of the cell assembly to stop the supply of power to the device, and the battery pack enters the sleep mode. If the battery pack receives a valid response from the device, the battery pack remains in the wake mode. While in the wake mode, the charge and discharge control modules **515** and **520** remain on, the battery pack provides a connection to the positive terminal of the cell assembly to provide power to the battery pack's power terminals, and the battery pack is able to power a device or be charged by the battery charger **30**.

The wake mode includes the NDM and the NCM. If the battery pack is connected to a device, is in communication with the device via the SDL, and has determined that the device is not a battery charger, the battery pack is configured to operate in the NDM. When in the NDM, the battery pack verifies that the voltages and temperatures of its cells are within predetermined operational limits. If the battery pack sends a message to the device and receives a valid response on the SDL, the battery pack continues to supply power through the power terminals. If the battery pack does not receive a valid response through the SDL for a predetermined number of communication cycles, the battery pack turns off the charge control module **515** and discharge control module **520** and enters the sleep mode.

When operating in the NDM, the battery pack also continuously monitors a discharge current from its power terminals. If the discharge current is not within predetermined operational limits for current discharge versus time, the battery pack turns off the charge control module **515** and the discharge control module **520** to terminate the discharge current and enters the sleep mode regardless of the logic level of the SDL or the presence of valid communication with the device controller **545**.

The battery pack also monitors the temperature of the battery cells in the cell assembly **505**. In order to compensate for thermal lag in the battery pack's temperature measurement system, the battery pack applies a temperature correction factor using an index value based on the discharge current. The correction factor is only used if the measured cell temperature is above 25° C. If the corrected temperature measurement is not within predetermined operational temperature limits, the battery pack turns off the charge control module **515** and the discharge control module **520** to terminate the discharge current and enters the sleep mode regardless of the logic level of the SDL or the presence of valid communication with the device controller **545**.

When the battery pack is discharging current, the battery pack continuously communicates with the device. For example, the battery pack controller **510** initiates and controls communication with the device. In other embodiments, the device controls communication with the battery pack (e.g., the device functions as a master device and the battery pack functions as a slave device). If the device fails to respond to the battery pack for the predetermined number of consecutive communication cycles (e.g., three cycles), the battery pack turns off the charge control module **515** and the discharge control module **520** to terminate the discharge current and then returns to the sleep mode.

Additionally, when the battery pack is discharging current, the battery pack also continuously monitors the voltage of each of the battery cells. If the voltage of one of the battery cells falls below a predetermined low voltage limit, the battery pack turns off the charge control module **515** and the discharge control module **520** to terminate the discharge cur-

rent and then enters the sleep mode regardless of the logic level of the SDL or the presence of valid communication with the device controller **545**.

When the battery pack terminates a current discharge process, the battery pack transmits a termination message to the device on the SDL that indicates why the current discharge process is being terminated. The battery pack transmits the termination message unless, for example, an over-current condition occurs during discharge which requires discharge current to be terminated in a period of time that precludes the battery pack from transmitting the termination message.

Additionally, if the battery pack enters the NDM as a result of being coupled to a configuration device, a special set of operating parameters are enabled. Configuration devices have the ability to request that the battery pack read and/or write values from individual memory locations (e.g., non-volatile memory locations) within the battery pack's memory **595**. Such an ability is particularly beneficial for devices which are assembled at multiple locations, or devices which have components that are manufactured at one or more locations but are assembled at another location. The ability to adjust operating parameters enables uniform operation of each of the devices, allows for the access of charge/discharge information stored within the memory, and allows for the modification of, for example, cell-specific charging parameters. The configuration device is a dedicated device or is incorporated into a device such as the battery charger **30** or a cleaning device. The configuration device includes a user interface that is configured to display operating parameters of the battery pack and allow a user to adjust the operating parameters of the battery pack. The configuration device is configured to request that the battery pack provide specific operating parameters or the contents of a specific memory location. The configuration device is also configured to request that the battery pack adjust a specific operating parameter or the value of a specific memory location to a value provided by the configuration device. For example, calibration data stored within the battery pack's memory can be read or modified, or the charge/discharge cycle count data can be retrieved. In other embodiments, the configuration device is configured to verify that the value of a memory location has been adjusted by requesting that the battery pack provide the adjusted memory value to the configuration device.

If the configuration device requests information from the battery pack, the battery pack remains as the master device during communications. The battery pack initiates communications with the configuration device, and the configuration device responds to the communications from the battery pack. If the configuration device requests that the battery pack provide the value of a particular memory location, the battery pack complies but responds to the request on the next communication cycle. In some embodiments, the configuration device initiates communication with the battery pack.

When the battery pack is operating in the NCM, the battery pack controls the charging operations. However, the battery charger **30** does not completely relinquish charging control to the battery pack. For example, the battery charger determines whether to terminate a constant-voltage charge during a charging process. The battery pack stores cell-specific charge parameters in its non-volatile memory and provides charging process information to the battery charger **30** for use during the charging process. When the battery pack is receiving a charging current, the battery pack continuously communicates with the battery charger **30**. If the battery charger **30** fails to receive messages from the battery pack for the predetermined number of communication cycles, the battery charger **30** turns off the SEPIC converter module **420** and removes voltage from the charging terminals.

The battery pack measures the voltage of each of the cells in the cell assembly **505** during the NCM. When one of the cells within the cell assembly **505** reaches a specified cut-off voltage, the battery pack requests that the battery charger **30** enter a constant-voltage charge mode. After the battery charger receives the request to enter the constant-voltage charge mode, the charging process is controlled by the battery charger **30**.

While in the constant-voltage charge mode, the battery charger **30** provides a constant voltage to the terminals of the battery pack and monitors the charge current. If the charge current falls to a predetermined limit, the battery charger **30** terminates the charging process, and the battery pack turns off the charge control module **515** and the discharge control module **520** to terminate the charging current and enters the sleep mode.

While in either the constant-voltage charge mode or the constant-current charge mode, the battery pack also measures the temperatures of the cells within the cell assembly. Based on the battery cell temperatures, the battery pack requests normal charge parameters (i.e., NCM parameters), or reduced current charge parameters, or turns off the charge and discharge control modules **515** and **520** to terminate the charging current temporarily until temperatures of the battery cells return to predetermined operational limits. If the battery pack indicates to the battery charger **30** (e.g., via the SDL) that a cell temperature within the battery pack cell assembly is outside of a predetermined temperature range, the battery charger **30** turns on the LED indicator as previously described and waits for the cell temperatures to normalize and the battery pack to again request the charging current.

Depending on the charging mode (e.g., constant-current or constant-voltage charging mode), a plurality of redundant checks are performed by either the battery pack or the battery charger **30** while the other is controlling the charging process. During the NCM, the battery charger **30** monitors the overall pack voltage and controls switching from the constant-current charging mode to the constant-voltage charging mode if the battery pack does not request a change in charging modes, and the battery pack voltage is within the predetermined voltage limits for the constant-voltage charging mode. Similarly, during constant-voltage charging mode, the battery pack monitors battery cell voltages and the overall pack voltage. If either the cell voltages or overall pack voltage satisfies predetermined limits for the battery pack being fully charged, the battery pack turns off the charge and discharge control modules **515** and **520** to terminate the charging current and enters the sleep mode.

The battery pack and battery charger **30** also include charge timers. Both of the charge timers are operational any time that a battery pack is being charged, including idle periods when battery cell temperatures temporarily prohibit further charging. If the battery pack charge timer exceeds a predetermined time limit, the battery pack turns off the charge and discharge control modules **515** and **520** to terminate the charging current and enters the sleep mode. Additionally or alternatively, if the battery charger charge timer exceeds a predetermined time limit, the battery charger **30** transmits a message to the battery pack and turns off the SEPIC converter module **420** to remove voltage. The battery charger **30** is also configured to turn the LED indicator **320** on and off to indicate the time-out condition. When the battery pack terminates a charging process, the battery pack transmits a termination message to the battery charger **30** on the SDL that indicates why the charging process is being terminated.

As previously described, the battery pack **50** is configured to be coupled to any of a plurality of devices. FIGS. **19-23** illustrate an electrically powered cleaning device, such as a stick-type vacuum **20** which receives power from the battery pack **50**. In some embodiments, the vacuum cleaner **20** and the battery pack **50** have a combined weight of less than approximately 7.5 pounds. The vacuum cleaner **20** includes a handle portion **805**, a body portion **810**, and a base or nozzle base portion **815**. In some embodiments, the vacuum cleaner **20** includes a hose or other attachments.

The handle portion **805** includes a first section **820** and a second section **825**. The first section **820** is oblique with respect to the second section **825** and includes a grip portion **830** (FIG. **21**). The grip portion **830** is on an opposite side of the first section **820** as a power switch or selection device **835**. In some embodiments, the grip portion **830** extends completely or almost completely around the first section **820**. The first section **820** of the handle portion **805** also includes a capacitive touch sensor for determining whether a user is touching the handle portion **805**. If the user is touching the handle portion **805**, the vacuum cleaner **20** operates as selected using the power switch **835**. If the user is not touching the handle portion **805**, the vacuum cleaner **20** reduces the speed of a motor/fan assembly **840**. By reducing the speed of the motor/fan assembly **840** (e.g., by reducing the current provided to the motor/fan assembly **840**), the vacuum cleaner **20** is able to conserve power when the user is away from the vacuum cleaner **20**.

The second section **825** of the handle portion **805** includes, among other things, a plurality of indicators **845** for providing indications to a user related to the operational mode of the vacuum cleaner **20**. In some embodiments, the handle portion **805** includes a first LED indicator and a second LED indicator. The first LED indicator provides an indication to a user related to whether suction is active for the vacuum cleaner **20**. The second LED indicator provides an indication to the user related to whether suction and a brush roll are active for the vacuum cleaner **20**. When the vacuum cleaner **20** is off or in an inactive state, neither the first nor the second LED indicators is in an illuminated state. When the vacuum cleaner **20** is in a suction only operational mode, the first LED indicator is in an illuminated state. When the vacuum cleaner **20** is in a suction and brush roll operational mode, the second LED indicator is in an illuminated state. The operational mode of the vacuum cleaner **20** is set by the power switch **835**, which is manipulable by a finger of a user while grasping the first section **820** of the handle portion **805**. In some embodiments, the switch **835** is rolled by a user into a plurality of positions corresponding to operational modes of the vacuum cleaner **20**.

In some embodiments, the handle portion **805** is removably coupled to the body portion **810**. For example, for storage or transport purposes, the handle portion **805** is detachable from the body portion **810**. In such embodiments, the handle portion **805** is coupled and secured to the body portion **810** via friction only. In other embodiments, a screw or other suitable fastening device is used to secure the handle portion **805** to the body portion **810**. As shown in FIG. **24**, the handle portion **805** also includes a plurality of electrical connectors **850** located at an interface **855** between the handle portion **805** and the body portion **810**. The electrical connectors **850** connect the handle portion **805** to the body portion **810** such that electrical signals related to the operation of the vacuum cleaner **20** are provided to the body portion **810** to control, for example, the motor/fan assembly **840**.

The body portion **810** includes a recess **860**, a fuel gauge **865**, the motor/fan assembly **840**, and a refuse chamber **870**. In some embodiments, the body portion **810** also includes a cyclonic separator. The recess **860** is shaped and configured to receive the battery pack **50**, and is positioned along a centerline or axis (e.g., a first axis as described below) of the body portion **810**. Such a positioning of the recess improves the balance, steering, and compactness of the vacuum cleaner **20**. The recess **860** includes a plurality of electrical connectors similar to the electrical connectors **310** shown in FIG. **12** with respect to the battery charger **30** for electrically connecting the battery pack **50** to the vacuum cleaner **20**. As described above, the fuel gauge **865** is configured to provide an indication to the user of the charge level of the battery pack **50** inserted into the vacuum cleaner **20**. In the illustrated embodiment, the fuel gauge **865** is positioned above the recess **860**. The fuel gauge **865** is oblique with respect to the second section **825** of the handle portion **805** such that a user is able to read the fuel gauge **865** during normal operation of the vacuum cleaner **20** without having to divert his or her attention from operating the vacuum cleaner **20**. In some embodiments, the fuel gauge **865** is located in the base portion **815** of the vacuum cleaner **20**.

The motor/fan assembly **840** is positioned below the battery pack **50** and the fuel gauge **865**. Such an arrangement between the battery pack **50** and the motor/fan assembly **840** is advantageous because airflow from the motor/fan assembly **840** provides cooling to the battery pack **50** and associated electronics. In some embodiments, the motor is a vertical brushless DC motor ("BLDC"). In other embodiments, different types of AC or DC motors are used, such as a brushed DC motor, a stepper motor, a synchronous motor, or other motors which use permanent magnets. In some embodiments, the body portion **810** also includes a diffuser, such as the diffuser disclosed in U.S. Pat. No. 7,163,372, entitled "DIFFUSER FOR A MOTOR FAN ASSEMBLY," the entire contents of which are hereby incorporated by reference.

The refuse chamber **870** is positioned below the motor/fan assembly **840**, and is removably coupled to the body portion **810**. In the illustrated embodiment, the refuse chamber **870** is bagless and includes a latching mechanism **875** (FIG. **25**), which secures the refuse chamber **870** to the vacuum cleaner **20**. The refuse chamber **870** also includes a lower portion having a latch **880** for emptying the contents of the refuse chamber **870** and an inlet **885** for receiving refuse.

A lower end of the body portion **810** includes an interface for attaching the body portion **810** to the base portion **815**. The base portion **815** includes a corresponding interface (FIG. **26**) for attaching to the body portion **810**. The interface includes, among other things, two terminals **890** and **895** for providing power to the base portion **815**, and an outlet **900** for providing refuse to the body portion **810**. The interface between the body portion **810** and the base portion **815** allows the vacuum cleaner **20** to stand upright without external support. For example, the vacuum cleaner **20** is operable in an upright working position in which the vacuum cleaner **20** can be operated without a user supporting the handle portion **805** or the body portion **810**. The base portion **815** is capable of being detached from the body portion **810** without the use of a tool, such as a screwdriver.

The base portion **815** also includes a multi-axis pivot joint **905**. In alternative embodiments, a ball joint is employed. The pivot joint **905** allows the handle and body portions **805** and **810** of the vacuum cleaner **20** to pivot with respect to the base portion **815**. For example, the pivot joint **805** allows for pivotal movement of the handle and body portions **805** and **810** about a first axis **910** parallel to a cleaning surface. Pivotal movement about the first axis **910** allows the handle and body portions **805** and **810** to be moved from a position approxi-

mately perpendicular to the base portion **815** to a position approximately parallel to the ground. For example, the handle and body portions **805** and **810** of the vacuum cleaner **20** are able to be moved through an angle of between approximately 0.0° and approximately 90.0° with respect to the base. In other embodiments, the handle and body portions **805** and **810** are pivotable through larger angles.

The handle and body portions **805** and **810** are also pivotable along a second axis **915**. The second axis **915** is approximately perpendicular to the first axis **910** and is approximately parallel to both the handle and body portions **805** and **810** of the vacuum cleaner **20**. Pivotal movement about the second axis **915** provides additional control and maneuverability of the vacuum cleaner **20**. The base portion **815** also includes a first wheel **920** and a second wheel **925** which provide rolling movement of the vacuum cleaner **20** along a cleaning surface following the application of an external force by a user. The first and second wheels **920** and **925** are coupled to the base portion **815** along the first axis **910**. The base portion **815** includes a suction inlet **935** on an underside of the base portion **815**. The suction inlet **935** includes an aperture or notch **940** which allows larger objects (e.g., cereal and similarly sized refuse) to enter the suction inlet **935** without requiring a user to lift the vacuum cleaner **20**. In some embodiments, airflow through the base portion **815** is preconditioned.

The base portion **815** includes a brush roll motor (not shown) for rotating a brush roll **945**. In one embodiment, the base portion **815** is implemented in a manner similar to that described in U.S. Pat. No. 5,513,418, entitled "SUCTION NOZZLE WITH DUCTING," the entire contents of which are hereby incorporated by reference. In other embodiments, the base portion is implemented in a manner similar to that described in U.S. Pat. No. 7,100,234, entitled "SUCTION NOZZLE ASSEMBLY," the entire contents of which are also hereby incorporated by reference. The brush roll motor is selectively activated by a user. For example, when the user selects the suction only operational mode for the vacuum cleaner **20**, the brush roll motor is in an off state and the brush roll does not rotate. Such an operational mode is often used on cleaning surfaces such as, for example, hardwood floors. When the user selects the suction and brush roll mode, the brush roll motor is in an on state and the brush roll rotates. Such an operational mode is often used on carpeted surfaces. In some embodiments, the vacuum cleaner **20** is configured to provide at least approximately 6 air Watts of power at the suction inlet **935** of the base portion **815**.

FIGS. **27-30** illustrate the battery pack **50** coupled to the hand-held vacuum **15**. The hand-held vacuum **15** includes a body **1105**, a handle **1110**, and a refuse chamber **1115**. The body **1105** includes a nozzle **1120**, a suction inlet **1125** (FIG. **30**), a suction motor/fan assembly **1130**, and a recess **1135**. The recess **1135** is sized and configured to receive the battery pack **50**. The battery pack **50** couples to and electrically connects to the hand-held vacuum **15** in a manner similar to that described above with respect to the stick-type vacuum **20**. The handle **1110** is integrated into the body **1105**, and is positioned between the recess **1135** and the nozzle **1120**. A junction of the handle **1110** and the nozzle **1120** includes a switch **1140** and a fuel gauge **1145**. The switch **1140** includes, for example, a first position (e.g., an 'ON' position) and a second position (e.g., an 'OFF' position) for controlling the operation of the hand-held vacuum **15**. In other embodiments, the switch **1140** includes additional positions corresponding to additional operational modes of the hand-held vacuum **15**, such as a high-speed setting and a low-speed setting for the motor **1130**. The fuel gauge **1145** of the hand-held vacuum **15** operates in a manner similar to the fuel gauge **865** described above with respect to the stick-type vacuum **20**.

In some embodiments, the hand-held vacuum **15** is configured to provide at least 13 air Watts of power at the suction inlet **1125**. The nozzle **1120** also includes a crevice/brush tool **1150** coupled to the nozzle **1120**. In the illustrated embodiment, the crevice/brush tool **1150** is pivotally coupled to the nozzle **1120**. When in a storage position, the crevice/brush tool **1150** is pivoted to a position clear of the suction inlet **1125** on an underside of the nozzle **1120**. When in a use position, the crevice/brush tool **1150** is pivoted from the storage position such that it is substantially in front of the suction inlet **1125**. In other embodiments, the crevice/brush tool **1150** is removably coupled to the nozzle **1120** or another portion of the hand-held vacuum **15**. The refuse chamber **1115** is positioned between the motor **1130** and the nozzle **1120**. The refuse chamber **1115** is, for example, frictionally coupled to the hand-held vacuum **15** or coupled via a latching mechanism. The refuse chamber **1115** includes an inlet (not shown) for receiving refuse from the nozzle **1120**. In the illustrated embodiment, the refuse chamber **1115** is bagless. In other embodiments, the refuse chamber **1115** includes a bag or similar disposable storage accessory.

Although the battery pack **50** has been described primarily with respect to its interconnections and coupling to battery chargers, stick-type vacuums, and hand-held vacuums, the battery pack **50** is configured to be coupled to the other devices in the cleaning system **10** illustrated in FIG. **1**. For example, the battery pack **50** is configured to be coupled to and power the bagless upright vacuum **25**, the bagged upright vacuum **35**, the carpet cleaner **40**, and the canister vacuum **45**. In some embodiments, one or more of the devices illustrated in FIG. **1** include a height-adjustable handle or body portion. Additionally, the specific manner and techniques for connecting the battery pack **50** to these devices is not described. However, in some embodiments, the interconnections between the battery pack **50** and the devices are similar to the interconnections described above with respect to the stick-type vacuum **20** and the hand-held vacuum **15**, although specific operating parameters and characteristics vary among the devices.

In some embodiments of the invention, when the battery pack **50** is not coupled to the battery charger **30**, the battery charger **30** is used to provide power to additional devices. For example, the battery charger **30** is configured to provide power to devices such as those illustrated in FIGS. **31-39**. The devices include a night-light **1200**, a kitchen timer **1205**, a clock **1210**, an audio storage device dock **1215**, an air ionizer, freshener, or fan **1220**, an LCD screen **1225**, a USB charging station **1230**, an indoor weather station **1235**, and a mobile phone charger or speakerphone **1240**. In other embodiments, the battery charger **30** is configured to charge additional devices. Each of the devices **1200-1240** includes terminals similar to those described above with respect to the battery pack **50** for coupling to the battery charger **30**, or an adapter is provided to connect the devices **1200-1240** to the battery charger **30**. In some embodiments, the battery charger **30** is configured to both power at least one of the devices **1200-1240** and charge a battery pack **50**. In such embodiments, the battery charger **30** includes either a recess for receiving a battery pack **50**, or the device includes an interface for electrically connecting the battery pack **50** to the battery charger **30**.

Thus, the invention provides, among other things, a cordless, battery-powered system of electronic devices, such as a system of cleaning products. Each of the devices is powered by a battery pack which is interchangeable among the

devices. Various features and advantages of the invention are set forth in the following claims.

What is claimed is:

1. A cordless vacuum cleaner, comprising:

a nozzle base portion having a suction inlet;

a body portion positioned above the nozzle base portion and including a battery pack recess, the battery pack recess sized to receive a lithium-based battery pack, the battery pack including a battery pack housing, a portion of the battery pack housing being insertable into the battery pack recess, the battery pack being selectively removably coupled to the body portion of the vacuum cleaner, the body portion being pivotable relative to the nozzle base portion;

a first power terminal and a second power terminal, the vacuum cleaner configured to receive power from the battery pack over the first power terminal and the second power terminal;

a communication terminal, the vacuum cleaner configured to communicatively connect to the battery pack over the communication terminal;

a vacuum motor powered by the battery pack and configured to provide a suction force at the suction inlet;

a brush roll motor powered by the battery pack and configured to provide rotational movement to a brush roll,

wherein the vacuum cleaner is configured to operate in a first mode in which the vacuum motor is operable, and a second mode in which the brush roll motor and the vacuum motor are operable; and

a selection device configured to select the first mode or the second mode.

2. The vacuum cleaner of claim **1**, further comprising a fuel gauge configured to indicate a status of the battery pack, the fuel gauge external to the battery pack and positioned in at least one of the body portion and the nozzle base portion.

3. The vacuum cleaner of claim **1**, wherein the nozzle base portion includes an aperture which allows relatively larger objects to enter the suction inlet.

4. The vacuum cleaner of claim **1**, wherein the vacuum cleaner is a stick-type vacuum cleaner.

5. The vacuum cleaner of claim **1**, wherein the battery pack is positioned above the vacuum motor.

6. The vacuum cleaner of claim **1**, wherein the body portion is supportable by the nozzle base portion in a vertical position without external support.

7. The vacuum cleaner of claim **1**, wherein the selection device is located on a handle portion and is manipulable by a finger of a user.

8. The vacuum cleaner of claim **1**, further comprising a refuse chamber.

9. The vacuum cleaner of claim **8**, wherein the battery pack is positioned above the refuse chamber.

10. The vacuum cleaner of claim **9**, wherein the battery pack is positioned above the vacuum motor.

11. The vacuum cleaner of claim **8**, wherein the battery pack is positioned above the vacuum motor, and the vacuum motor is positioned above the refuse chamber.

12. The vacuum cleaner of claim **1**, wherein the battery pack is positioned along an axis of the body portion.

13. The vacuum cleaner of claim **12**, wherein the battery pack is positioned along a centerline of the body portion.

14. The vacuum cleaner of claim **1**, wherein the vacuum cleaner is configured to communicate serially with the battery pack.

15. The vacuum cleaner of claim **1**, wherein the vacuum cleaner receives a signal over the communication terminal related to a cell voltage of at least one of a plurality of lithium-based battery cells within the battery pack.

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